A COMPREHENSIVE ANALYTICAL APPROACH FOR ACHIEVING SUCCESSFUL BIODIVERSITY OFFSETS IN LATIN AMERICA

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Maria Jose Carreras Gamarra

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ABSTRACT

Interest in biodiversity offsets has grown over the past decade as a mechanism to achieve no net loss of biodiversity while economic development continues. In Latin America, the development of policies and tools for the regulation and design of biodiversity offsets have started to gain momentum and their implementation is proliferating at a fast pace. However, given the complexities and challenges associated, there appears to be a generalized failure to address biodiversity offset key issues (including biodiversity value measurements, consideration of a landscape context, and monitoring of results over time), and consequently, to develop appropriate offset interventions.

In this context, the purpose of this research was to provide a practical structured decision making tool for the implementation of successful biodiversity offset strategies through the adequate assessment of offset gains and project impacts. This tool was framed according to the needs and preferences of stakeholders involved with biodiversity offsets in Latin America, and developed following an iterative process of consecutive steps that feed into each other as a way of providing the necessary data for informing structured decisions.

Using the identified stakeholder perspectives as assessment criteria (together with established frameworks of indicator desirable properties and attributes), current metrics for measuring biodiversity equivalencies were identified, characterized, and analyzed in terms of their pros, cons, weaknesses, and advantages when applied

to offset projects in Latin America. Using the obtained results as a baseline of the current state of offset metrics, a logic model for assessing offset performance across time and over space was developed, consisting of a set of landscape indicators, scoring procedures, and value calculations. The logic model developed and the offset metrics assessed were both evaluated by comparing the results obtained when measuring potential project impacts and offset gains in a peatland ecosystem in northern Peru. The results obtained showed that current offset metrics, on their own, are not adequate enough to determine equivalences, and that the logic model acts a supplementary tool to identify offset areas that are equivalent to the impact area in terms of the broader landscape context.

As a final result, the different products obtained throughout this research were integrated into a practical and structured decision making tool for the evaluation of biodiversity offset success in Latin America. Individual projects could potentially work from this framework, considering the achievement of no net loss of biodiversity as an ultimate common goal. This final result ultimately contributes to the achievement of successful biodiversity offset strategies and acts as a platform to evaluate the success of these strategies over time.

BIBLIOGRAPHICAL SKETCH

Maria Jose Carreras was born June 15, 1988 in Lima, Peru. She received a Bachelor of Science in Biology degree from La Molina National Agrarian University, in her home country. After being awarded a Fulbright Scholarship, Maria Jose enrolled in a two-year Master of Science program in the Department of Natural Resources at Cornell University in 2014, where she researched the role and performance of biodiversity offsets in Latin America.

Outside of academics, Maria Jose has broad experience developing both investment projects for biodiversity conservation and management and environmental impact studies throughout South America. In Peru, she has led several biodiversity assessments focused on national and international compliance standards (e.g., IFC's Performance Standards, Equator Principles). She did a summer consulting internship at Ecology and Environment Inc. in 2015 as an Environmental Specialist, and has been working for the past years on projects focused on a critical review of biodiversity offset policies, marine spatial planning, and climate mitigation strategies through agroforestry across Latin America.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BBI	Biodiversity Benefits Index
BBOP	Business and Biodiversity Offsets Programme
BOCS	Biodiversity offset case study
BSI	Biodiversity Significance Index
BSS	Biodiversity Significance Score
BV	Biotope Valuation
CAI	Core Area Index
CBD	Convention on Biological Diversity
CLUMPY	Clumpiness Index
CONNECT	Connectance Index
CS	Conservation Significance
CSI	Conservation Significance Index
DEADP	Department of Environmental Affairs and Development Planning
DEFRA	Department for Environment, Food and Rural Affairs
ED	Edge Density
EDJI	Ecological Dow Jones Index
EIA	Environmental Impact Assessment
EU	European Union
FOEN	Federal Office for the Environment
GDI	Generic Diatom Generalized Index
GIS	Geographic Information System
GYRATE_AM	Correlation Length Index
HH	Habitat Hectares
HU	Habitat Units
IBA	Important Bird Area
ICMM	International Council on Mining and Metals
IDB	Inter-American Development Bank
IFC	International Finance Corporation
IJI	Interspersion/Juxtaposition Index
IUCN	International Union for the Conservation of Nature
LC	Landscape Context
MAFE	*Mapeo de Formulas Equivalentes*
NGOs	Non-Governmental Organizations
NRE	Victorian Department of Natural Resources and Environment
NSW	New South Wales
OPLM	Offset Performance Logic Model
OPV	Offset Performance Value
PAFRAC	Perimeter-area fractal dimension Index
PS	Performance Standards
PS6	Performance Standard 6
SEB	Significant Environmental Benefit
SHDI	Shannon's Diversity Index

SPLIT	Splitting Index
SR	Systematic Review
TBC	The Biodiversity Consultancy
UD	Units of Global Distribution
UK	United Kingdom
UMAM	Uniform Mitigation Assessment Method
US	United States
VC	Vegetation Condition
VCB	Vegetation Condition Benchmark

1. CHAPTER 1: INTRODUCTION

1.1. Situation

Biodiversity offsets are defined as “measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development” (International Finance Corporation [IFC], 2012, p. 2). The implementation of offset strategies is currently being not only encouraged, but also required by several national regulations (e.g., Peru, Brazil, and Colombia), policies (e.g., the European Union [EU] No Net Loss initiative for 2015, which is part of the EU 2020 Biodiversity Strategy), financial institutions (e.g., IFC, Inter-American Development Bank [IDB], Asian Development Bank [ADB]), and industry best practices (e.g., International Council on Mining and Metals [ICMM]).

In the case of the IFC, one of many other contexts where biodiversity offsets are required, its set of Performance Standards (PS)[1] have been adopted by 67 banks and financial institutions (operating in 100 different countries) since 2003, demanding clients that seek project funds of over US$ 10 million to comply with them (ten Kate & Barcellos Harris, n.d.). In particular, Performance Standard 6 (PS6, “Biodiversity Conservation and Sustainable Management of Living Natural Resources”), emphasizes the use of the mitigation hierarchy framework as a tool for managing impacts arising from project development in order to obtain a no net

[1] One of the most common reference points for banks that attempt to manage environmental and social risks when financing projects, as part of their strategic commitment to sustainable development (PricewaterhouseCoopers, 2010).

loss of biodiversity (The Biodiversity Consultancy [TBC], 2012). According to this framework, after applying appropriate avoidance, minimization, and restoration measures, projects should rely on biodiversity offsets to mitigate any significant adverse residual impacts (IFC, 2012).

Among the implications of offset implementation, several authors have pointed out the different benefits and opportunities related to the promotion of biodiversity conservation and sustainable development. For example, as indicated by ten Kate, Bishop, and Bayon (2004), biodiversity offsets represent an important tool for maintaining or enhancing environmental values in situations where development projects imply negative residual environmental impacts, aiming to provide a no net loss and ultimately a net gain of biodiversity while economic development continues. Moreover, as defined by Stöbener (2013), offsets "effectively place an economic value on something that was previously economically invisible, increase reliability of long-term conservation projects, improve conservation awareness among developers and strengthen conservation partnerships."

Together with environmental fiscal reforms, payments for ecosystem services, green markets, biodiversity in climate change funding, and biodiversity in international development finance, biodiversity offsetting is one of the six Innovative Financial Mechanisms outlined by the Convention on Biological Diversity (CBD) (Godoy, 2014). The treaty has been signed by 194 countries since 1993, including most of Latin American nations. Currently approximately one-fifth of them are implementing biodiversity offsetting mechanisms, and about 45 programs are in operation, representing investments of between US$ 2.4 and US$ 4.0 billion (Godoy, 2014). Trends suggest that more governments will be introducing or exploring policies regarding biodiversity offsets; more companies will be voluntarily implementing offsetting mechanisms; more bank lenders and investors will be demanding biodiversity offsets as a condition for accessing specific credits; and more non-governmental organizations (NGOs) and social civil groups will be encouraging the development of this type of management strategy (ten Kate, von Hase, Boucher, Cassin, & Victurine, 2011).

With interest in biodiversity offsets increasing worldwide, the development of offset policies and frameworks for environmental purposes have gained attention in recent years (McKenney & Kiesecker, 2010). In this context, tools for their regulation and implementation are continually being developed by national governments, public finance institutions (e.g., IFC, European Investment Bank, Asian Development Bank, etc.), specific private companies (e.g., Rio Tinto), and conservation institutions (e.g., Business and Biodiversity Offsets Programme [BBOP]). Are these policies and frameworks feasible and adequate enough for developing successful compensation strategies and thus achieving the promise of biodiversity offset schemes? Evidence suggests the opposite.

1.2. Complication/Problem

In most of the existing biodiversity offset frameworks developed in contrasting regulatory contexts, detailed guidance regarding offset implementation and evaluation remains elusive (McKenney & Kiesecker, 2010), and several offset policies have been criticized for their poor track records of effective implementation (Quétier & Lavorel, 2011). For example, an analysis developed by Quétier, Regnery, and Levrel (2014) shows that the French policy, in spite of its laudable ambition, does not address the institutional arrangements and science base needed to reach the objective of no net loss.

There appears to be a generalized failure to ensure that biodiversity is adequately measured, and consequently, that offset interventions are sufficient and appropriate (CEEweb for biodiversity, 2014). To address this criticism about the inadequate measurability of the biodiversity value that is lost or recreated, adequate information about the biodiversity value of the areas involved is required; however, the current related evidence base is patchy and not well investigated (Curran, Hellweg, & Beck, 2014). In the United States (US) and Australia, where biodiversity offsetting is most advanced, studies show that most offset strategies fail to replace what was impacted, with only between a third and half of restoration offsets being reported as successful, and even less than that in the case of recreation offset strategies (Suding, 2011). In the same line, a study developed by Curran, Hellweg, and Beck (2014) does not support the current form of implementation of offsets in old growth vegetation, predicting a high probability of failure (up to 82%),[2] which is not accounted for in offset policies; a number of previous studies on the success rate of offsetting schemes supports these findings (Curran, Hellweg, & Beck, 2014).

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[2] The study mainly focuses on restoration offsets.

Regarding the above, biodiversity value measurements and the overall assessment of the equivalence between offset gains and impact losses can be considered one of the most important and challenging key issues that fail to be properly addressed (Gonçalves, Marques, Velho Da Maia Soares, & Pereira, 2015; Quétier & Lavorel, 2011); and unfortunately, that cascades down with the potential of affecting all other offset challenges (Gonçalves, Marques, Velho Da Maia Soares, & Pereira, 2015). Although a set of robust metrics that effectively represents the biodiversity values at stake and accurately determines the offsetting requirements is critical for achieving the promise of biodiversity offsetting (Burgin, 2008; IFC, 2012), "most offset programs methods for assessing currency are in their infancy" (Kiesecker et al., 2009, p. 82). These are usually characterized as being either too rigid to properly address the ecological context of specific impacts and offsets, or too open to non-objective judgments (Saenz et al., 2013).

For wetland offsets, for example, methodological developments for biodiversity valuing have been ongoing for more than two decades throughout the US, and there are more than 100 individual tools available for their assessment (Bartoldus, 1999). Nevertheless, despite their proliferation, all are subject to criticism, and only a few are implemented due to the associated high costs and complex application (Kusler, 2006). This issue has been pointed out repeatedly by different authors in several additional investigations and publications (e.g., Gordon, 2008; Kiesecker et al*.,* 2009; Ruhl, Kraft, & Lant, 2009). As stated by Gonçalves, Marques, Velho Da Maia Soares, and Pereira (2015) "it is essential that the research community contribute to establish a sound theoretical framework on how to measure biodiversity offsets" (p. 65).

Robust and appropriate metrics for assessing ecological balance should be accompanied by a method for assessing offset performance and success both over time (through monitoring programs), and across space (using a landscape approach). Regarding the former, as highlighted by Bull, Suttle, Gordon, Singh, and Milner-Gulland (2013), biodiversity offset schemes have been inconsistent in meeting conservation objectives because of the challenge of ensuring, among others, effective monitoring and full compliance: "if ecological outcomes are not monitored then it is difficult to demonstrate no net loss" (p. 376).

On the other hand, one of the main drawbacks to several of the currently existing methods for assessing biodiversity values and monitoring their success is that they do not take into account a landscape[3] context when measuring losses and gains (Bruggeman, Jones, Lupi, & Scribner, 2005; Curran, Hellweg, & Beck, 2014). According to Gardner and von Hase (2012), "it is essential that the design and implementation of project-level offsets takes account of the wider-landscape context" (p. 6) when determining the most appropriate set of offset activities and locations in the ecological landscape; this, considering that biodiversity losses and

[3] For the purpose of this thesis, a landscape is defined as: "A mosaic where a cluster of local ecosystems is repeated in similar form over a kilometer-wide area. A landscape is characterized by a particular configuration of topography, vegetation, land use, and settlement pattern that delimits some coherence of natural, historical, and cultural processes and activities" (McNeely & Scherr, 2003, p. 275).

gains cannot be estimated in isolation, as they need to account for the regional significance of biodiversity values. Even more, as stated by Kiesecker et al. (2009), selecting offset location through the use of a strategic approach such as landscape level planning potentially increases the associated biodiversity benefits.

The lack of use of adequate metrics for measuring biodiversity equivalencies together with appropriate methods for assessing offset performance over time and across space, ultimately and jointly results in an absence of proven successful offset outcomes, thus hampering the achievement of the no net loss of biodiversity goal.[4] Even worse, when offsets do not achieve equivalence with respect to what is being lost, they ultimately result in an increased loss of biodiversity, being inevitably perceived as a “license to trash nature” (ten Kate, Bishop, & Bayon, 2004).

In Latin America, the development of policies and tools for the regulation and design of biodiversity offsets have started to gain momentum and their implementation is proliferating at a fast pace (Sarmiento, 2013; TBC, 2012; Villarroya, Barros, & Kisesecker, 2014). A study on policy development for environmental licensing and biodiversity offsets in Latin America developed by Villarroya, Barros, and Kisesecker in 2014, shows that countries that make up 85% of all Central and South America have enacted Environmental Impact Assessment (EIA) regulations in the last decade, most enabling the use of offsets, and four

[4] For the purpose of this research, a successful offset strategy is considered one that achieves a no net loss, or net gain, of biodiversity.

have developed specific policies that regulate the implementation of this strategy. Chile can be added to this list, with a regulatory requirement to offset issued in 2014. What results will the development of biodiversity offsetting schemes in Latin America generate? What is needed and what is of utmost importance in the short-term to promote the development of successful biodiversity offset strategies in the region? Unlike the US, Australia, and European countries where biodiversity offsetting is most advanced (Azzopardi, 2014), the nascent state of this strategy in Latin America offers the opportunity to develop more sophisticated tools using the lessons learned elsewhere, allowing offsets to mature and deliver the promised benefits locked behind the concept.

1.3. Solution/Way Forward

It seems clear that for the adequate development of biodiversity offset strategies in Latin America, looking to achieve positive results for conservation, an appropriate and defensible accounting model for assessing offset performance needs to be developed and promoted as an accessible and practical tool among stakeholders (McKenney & Kiesecker, 2010). The key point is to develop work and research to rapidly progress towards sound and robust offset performance assessment methods, providing the necessary information for effectively measuring the equivalence between biodiversity offset gains and residual project impacts, in terms of complexity, cost, and time (Söderman, 2006).

Considering the above, my thesis presents a suite of the various current metrics that have been proposed for assessing equivalencies, including an analysis of the implications and tradeoffs of their use within a Latin American context, addressing the perspectives of the region's stakeholders. Using the obtained results as a baseline and first step of a continuous and structured process, a specific logical model for assessing offset performance across time and space is proposed (encompassing a landscape scale approach), seeking to overcome the identified gaps and limitations of currently existing tools. Afterwards, the different analyzed metrics and the developed model are assessed by comparing the results obtained when measuring project impacts and offset gains in a selected Latin American biodiversity offset case study (BOCS); finally, the different results obtained are integrated into a practical and structured decision making tool for the evaluation of biodiversity offset success in Latin America. Individual projects could potentially work from this framework, considering the achievement of no net loss of biodiversity as an ultimate common goal.

1.4. Research objectives

The goal of my research is to provide an appropriate, practical, and structured decision making tool for assessing the ecological equivalence between biodiversity impact losses and offset gains in Latin America over time and across space, as a means of achieving a no net loss of biodiversity. This overarching goal has been subdivided into five specific objectives specific to Latin America (Figure 1).

1. To identify the most relevant criteria and attributes against which to evaluate the adequacy of offset metrics by stakeholders.

2. To (a) identify and describe the various existing metrics for assessing equivalencies, and (b) analyze their pros, cons, gaps, advantages, disadvantages, and appropriateness when used in offset projects.
3. To develop a logic model for assessing offset performance over time and across space, through the use of a set of indicators and scoring procedures based on the size-condition-landscape context framework for conservation evaluation proposed by The Nature Conservancy (TNC, 2003).
4. To compare the results obtained when analyzing equivalences with different existing metrics and the developed logic model using a relevant biodiversity offset case study (BOCS).
5. To integrate the results obtained in a practical and structured decision making tool for the implementation of successful biodiversity offset strategies, including their regulation and evaluation.

As presented in Figure 1, my research objectives have been organized in a cyclic manner, as a means of potentially updating and improving the results over time. In this sense, the decision making tool for the regulation and evaluation of biodiversity offset success (Objective 5) will be evaluated and validated using the criteria presented as part of Objective 1, going through the whole cycle again (as needed). This established an iterative process that feeds back on itself, framed under the guidelines of adaptive management.

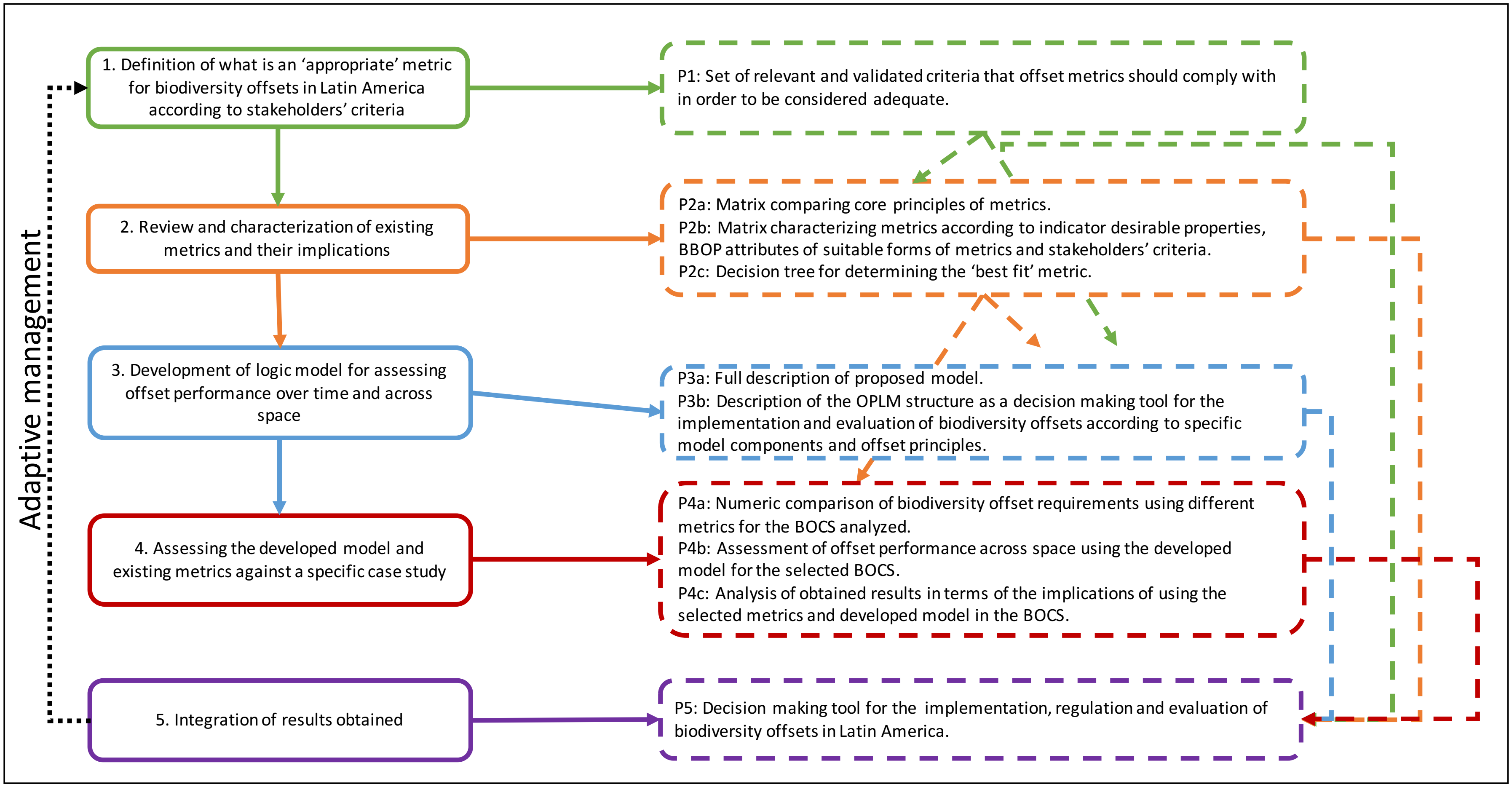

Figure 1 Research objectives and corresponding products

Key:
P = Research products; OPLM = Offset Performance Logic Model; BBOP = Business and Biodiversity Offset Program; BOCS = Biodiversity offset case study.

1.5. Research impact

As with other emerging conservation strategies, biodiversity offsetting must be supported by effective policies. Regardless of the potential benefits of offsetting, unless appropriate compensation is ensured, it is unlikely that offsetting will achieve the goal of no net loss of biodiversity. Moreover, if offset gains do not achieve equivalence to what is lost, they may result in an even greater loss of biodiversity. This problem is of special concern for most policy makers, environmental management planers, and conservation organizations in Latin America, a high priority region for mining exploration, attracting one third of global mining investments in 2010 (Ericsson & Larsson, 2011), where one fifth of the territory is reserved for biological conservation (World Bank, 2012).

Because of the continuous proliferation of offset guidance,[5] of offset international workshops,[6] and because of recent offset policy developments[7] in Latin America, the implementation of biodiversity offset strategies will continue to grow in the region, with or without adequate and effective tools for their development and evaluation. This will not only jeopardize the reputation and validity of this approach to conservation, but will also put at risk the same biodiversity values that are being targeted for conservation and management. In this context, my research aims to provide an effective tool for environmental management planners and practitioners in Latin America to implement

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[5] For example, BBOP's and the International Union for the Conservation of Nature's (IUCN) offset standards and principles.

[6] For example, the *Aplication of the Mitigation Hierarchy and Biodiveristy Offsets in EIAs for the development of Infraestructure and Sustainable Energy in Latin America* workshop, conducted in Peru in March 2016.

[7] For example, Peru's *Guidance for Biodiversity Offset Plan*, issued in March 2016, and Chile's guidelines for biodiversity offsetting within EIAs, issued in 2015.

when measuring the ecological equivalence of biodiversity offset gains with residual project impacts, where the existing frameworks for such processes are considered relatively limited. The intent is to contribute towards solving the technical problems related to biodiversity measurements in offsetting strategy contexts, thus providing more certainty of the final outcome of such approaches.

2. CHAPTER 2: RESEARCH FRAMEWORK

2.1. Conceptual outline

This subsection presents an outline of the concepts of biodiversity offsets, biodiversity offset metrics, and ecological equivalence. A brief description of the characteristics and implications of the use of these terms is included.

2.1.1. Biodiversity offset

Despite the existence of numerous definitions for biodiversity offset (Table 1), they all coincide in that this strategy should compensate for adverse biodiversity residual impacts (no net loss of biodiversity), and that it should produce quantifiable results. In this sense, according to its definition, offsets rely upon the accurate measurement of losses and gains, therefore requiring robust metrics (Burgin, 2008). This represents one of the main differences between a biodiversity offset strategy and a compensation measure. Compensation outcomes are not necessarily measurable, as they do not require the quantification of losses and gains, and therefore do not necessarily imply the achievement of no net loss.

In general, biodiversity offsets can be categorized according to three different types: like-for-like, like-for-better, and out-of-kind.

- **Like-for-like:** involves the management of the same type of biodiversity target the project is impacting, in ecological terms (type, amount, and condition over space and time) and in terms of conservation status or priority.

- **Like-for-better/trading up:** involves exchanges of impacts on lower-priority biodiversity areas for offsets in higher-priority biodiversity areas; the offset may target biodiversity of higher conservation priority than the biodiversity impacted (BBOP, 2012).
- **Out-of kind:** biodiversity type being gained is considered to be different to the biodiversity type being lost (i.e., different habitat/ecosystem types). It also refers to offset activities that remotely link to biodiversity, such as monetary payments and the production of goods and services. The achievement of no net loss in this case is very difficult to demonstrate, as there is not yet an accepted method for comparing and exchanging different types of biodiversity or different types of losses and gains.

Table 1 Common definition of biodiversity offsets

Definition	Reference
"Measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development."	IFC, 2012, p. 2
"Measures taken to compensate for any residual significant, adverse impacts that cannot be avoided, minimised and / or rehabilitated or restored, in order to achieve no net loss or a net gain of biodiversity."	BBOP, 2012, p. 1
"Conservation actions that seek to counterbalance residual impacts resulting from development with measurable conservation outcomes, with the aim of no net loss for biodiversity."	Kiesecker et al., 2009, p. 82
"Action aiming to offer a positive counterbalance to an irreducible harmful impact caused by a development project, so as to maintain the biodiversity in an equivalent or better state than that observed before the project begins."	Morandeau & Vilaysack, 2012, p. 4

The IFC (2012), BBOP (2012), and several other international institutions and offset policies indicate a general preference for like-for-like compensation strategies, which provide comparable functions. The preference for in-kind offsetting is based on the premise that the best way to ensure full and equivalent replacement of losses is to compensate with the same type of habitat, functions, and values. Taking this into consideration, my research focuses only on the like-for-like offset approach.

Most offset policies concur that the like-for-like approach must result in benefits that are additional to any existing values, emphasizing the 'additionality' principle: outcomes are demonstrably new and additional and would not have resulted without the offset, providing a new contribution to conservation (McKenney & Kiesecker, 2010). Where there is little or no 'additionality', offsets do not occur, and the residual impacts remain (TBC, 2012). Under this requirement, biodiversity gains can be achieved through several interventions categorized in two broad categories (Morandeau & Vilaysack, 2012): management strategies and conservation strategies.

- **Management strategies:** positive management actions that seek to improve biodiversity conditions of sites with different levels of degradation (BBOP, 2012). These actions generally bring an ecological gain, but the results remain uncertain at a first stage. Examples include: habitat re-creation (Natura2000); revegetation, regeneration, restoration, and enhancement (New South Wales Government, Australia); connecting separated habitats and buffering of already protected areas (U.S. Conservation Banking); among others.
- **Conservation strategies:** include actions that prevent further harm to biodiversity by slowing or stopping drivers of ongoing environmental degradation (arrested degradation), and interventions that guard biodiversity against known future risks (averted risk) (BBOP, 2012). These strategies offer greater

predictability, but the ecological added value in relation to the current/potential threats of the offset area needs to be demonstrated. Examples include: creation of protected areas, implementation of environmentally responsible management practices, avoidance of further permitted impacts, recovery from forest product harvesting and wildfires (Victoria Department of Natural Resource and Environment, Australia), among others.

Most offset frameworks do not favor one type of measure over the other, as it depends on the nature of the project's impacts and the condition of the site selected for the offset. It is a decision that needs to be taken on a case-by-case basis (Morandeau & Vilaysack, 2012). Nevertheless, several studies prohibit practitioners from implementing restoration or rehabilitation activities (management strategies) as part of an offsetting scheme. This group of strategies inherently has associated long time lags,[8] high levels of uncertainty, and an inevitable risk of failure (Curran, Hellweg, & Beck, 2014).

On the other hand, regarding conservation activities, these are only recommended in cases where arrested degradation and/or averted disturbance can be demonstrated. These include areas where rates of habitat loss and degradation are demonstrably high, and where no strong policies or regulations for biodiversity protection exist (Gibbons & Lindenmayer, 2007). Although challenging, this can be determined through

[8] Biodiversity values are initially lost at the impact site, and do not exist until they are restored at the offset site after long periods of time (TBC, 2012). This is specifically important in the case of wetlands and peatlands, where the organic matter takes a long time to regenerate and accumulate.

counterfactual scenario building, which involves answering the question: what would have occurred without the intervention?

2.1.2. Offset metrics/currencies

Metrics are surrogates, measurements that act as a substitute for a complete measurement of the total biodiversity found, or combinations of measurements, that together provide an assessment of the biodiversity value of a particular area. Metrics allow the biodiversity impact of a development to be quantified so that the offset requirement, and the value of the compensatory action, can be clearly defined (Department for Environment, Food, and Rural Affairs [DEFRA], 2011). At present, different metrics are being used to assess the equivalence of biodiversity offset gains with project impacts. These vary from very basic measures, such as area extent, to much more sophisticated quantitative indices of multiple biodiversity components (Dickie et al., 2013). Current metrics can be categorized under two principal approaches (DEFRA, 2011): singles metrics and compound metrics.

- **Single metrics:** only use one kind of attribute for assessing biodiversity value; habitat area, vegetation density, and biomass are a few examples. Although relatively easy to calculate and evaluate, single metrics provide really limited information for assessing the equivalence of biodiversity offset gains with project impacts. Such metrics rarely provide sufficient information about the quality of the area involved.

- **Compound metrics:** use multiple attributes to come up with a single figure or index. Because of their nature, these are more complex and potentially more accurate as a measure of biodiversity value (DEFRA, 2011). Habitat Hectares is a good example; this metric's score summarizes information about an area, including the relative condition of the vegetation and its spatial context within the landscape (McCarthy et al., 2004). Although the use of multiple attributes may result in a more comprehensive understanding of biodiversity losses and gains and the level of ecological equivalence achieved (Kiesecker et al*.,* 2009), making sense of the resultant information could be challenging if the results of the attributes used are not consistent in direction or magnitude. Besides, these metrics are usually intensive in terms of the input required to assess the offset target, requiring trained operators to ensure the required levels of consistency (DEFRA, 2011).

Regarding the above, in order to consider the investment in measuring conservation outcomes derived from the implementation of offset strategies as justifiable and viable, the selected assessment method and currency should not only be scientifically sound and rigorous, but also effective in terms of complexity, and practical in terms of cost and time (Bull, Suttle, Gordon, Singh, & Milner-Gulland, 2013). As suggested by the Environmental Audit Committee of the United Kingdom (UK) Government, metrics "must be sophisticated enough to reflect the biodiversity value of development sites, while remaining transparent and user-friendly" (Environmental Audit Committee, 2014, p. 2).

2.1.3. Ecological equivalence

There is no unique, shared, or legally based definition of the concept of ecological equivalence, being commonly a result of consensus of opinion of the stakeholders involved. In the field of compensation, ecological equivalence can be defined as an equal value of a biodiversity component, indicator or set of components, generally used to assess the relationship between the losses at the impacted site and the gains at the compensation site (Dickie et al., 2013). In this sense, and under the scope of no net loss of biodiversity, “an offset project is considered equivalent if it is designed and sized in order to achieve ecological gains which are at least equal to the loss at the impacted site” (Dickie et al., 2013, p. 3), in magnitude, approximate timing, and recipient population. Similarly, the BBOP considers ecological equivalence to be synonymous with the like-for-like principle, which refers to areas with highly comparable biodiversity components, in terms of species diversity, functional diversity and composition, ecological integrity or condition, landscape context, and ecosystem services.

None of the above definitions refer to ecological equivalence as achieving gains that are a 100% equal to what is being loss. Rather, these, as well as other directives and frameworks found in the literature, state that equivalence in biodiversity offsetting strategies involve complying with the like-for-like principle, where losses and gains are comparable in terms of type, quality, and value. It is important that a favorable status and overall coherence is ensured, resulting in an improvement in the extent or condition of the ecological network (DEFRA, 2011; Dickie et al., 2013).

2.2. Can all impacts be offset?

Most of the available literature agrees that there are limits to what can be offset: some residual impacts cannot be fully compensated due to the inherent vulnerability or irreplaceability of the affected biodiversity target (BBOP, 2012). Species extinction is the most commonly cited example of an impact that cannot be compensated. Despite the simple nature of this idea, beyond extinction, it is very difficult in practice to define limits to what impacts can be offset, mainly because the definition of what can be compensated involves making value judgments (Bull, Suttle, Gordon, Singh, & Milner-Gulland, 2012). For example, society might accept a scheme that treats some habitat types as interchangeable, as in offsets in the UK (DEFRA, 2011), but this same scheme may not be acceptable if it involves the loss of charismatic and/or threatened fauna species.

Pilgrim et al. (2013), proposed a process to evaluate how likely project impacts can be successfully offset. It is based on an assessment of the biodiversity conservation target (in terms of vulnerability and irreplaceability), magnitude of residual impact (in terms of severity, extent, and duration), offset opportunity, and feasibility. According to the results obtained, the strategy can range from unlikely to be appropriate to ‘offsetable’ with relatively low standard of proof, using a combination of categories of biodiversity conservation concern and likelihood of offset success.

2.3. Importance of a landscape context

BBOP's Principle 3 states that biodiversity offsets "should be designed and implemented in a landscape context to achieve the expected measurable conservation outcomes taking into account available information on the full range of biological, social and cultural values of biodiversity and supporting an ecosystem approach" (BBOP, 2012, p. 18). Some elements of biodiversity can only be measured relative to regional scales, and thus require a landscape perspective in order to be considered. This applies to many ecological or evolutionary processes (e.g., those relating to habitat connectivity), which should be accounted for loss/gain exchanges (BBOP, 2011). Moreover, the long-term viability of biodiversity at offset sites critically depends on the connectivity of such areas to other landscape elements through, for example, colonization and dispersal processes (Bennett, 2013).

Ecoagriculture Partners' Landscape Measures Resource Center presents a list of more than 20 benefits and strengths derived from placing offsets within a landscape level planning context (Buck, 2007). Examples of these benefits include: allows the potential impact to be better understood, as well as ways to manage it; ensures that regional or national conservation priorities are integrated into business planning; scales up the offset planning process to a larger, more productive one; anticipates and accommodates medium and long-term change (e.g., climate change); works along bioregional rather than political boundaries; and drives/underpins regional sustainability.

Despite its importance and derived benefits, one of the main drawbacks to several of the currently existing methods for assessing biodiversity values is that they do not take into account a landscape context (Bruggeman, Jones, Lupi, & Scribner, 2005). The same in the case of most current offset polices and regulations. As highlighted by McKenney and Kiesecker (2010), offset frameworks need to move beyond encouraging a landscape/watershed approach to making this planning a requirement, and like this contribute to regional, national, and/or global conservation priorities.

2.4. Biodiversity offsets in Latin America

Biodiversity offsets can be considered of special importance in Latin America, a region that concentrates a significant amount of biological diversity, and where the economy is principally based in primary extractive industries (Bovarnick, Alpizar, & Schnelli, 2010). Offset strategies potentially contribute to biodiversity conservation objectives, while simultaneously supporting the achievement of national development targets.

Despite the potential of biodiversity offsets in Latin America, there continues to be more activity in traditional payments for ecosystem services mechanisms than in offsets, compensation strategies, and banking systems (Madsen, Carroll, Kandy, & Bennett, 2011). Besides the lack of technical capacity and political will, one of the contributing factors to this issue is related to the lack of available scientific research about biodiversity offsetting schemes in Latin America. Most related studies are centered in the US and other developed countries. I conducted a thorough systematic literature review in September, 2015 using the Web of Knowledge platform to determine the number of scientific articles about biodiversity offsets that specifically focused on Latin American countries or regions. The search comprised the following keywords: Biodiversity offsets* and Latin America*, where the asterisk allowed finding those articles with derivations of the main word. Only five articles were found (Table 2).

Table 2 Scientific articles addressing biodiversity offsets in Latin American countries

Title	Authors	Year	Journal	Countries
A Framework for Implementing and Valuing Biodiversity Offsets in Colombia: A Landscape Scale Perspective	Saenz, S., Walschburger, T., González, J.C., León, J., McKenney, B., and Kiesecker, J.	2013	Sustainability	Colombia
Policy Development for Environmental Licensing and Biodiversity Offsets in Latin America	Villarroya, A., Barros, A.C., and Kiesecker, J.	2014	PLOS One	Argentina, Brazil, Chile, Colombia, Mexico, Peru and Venezuela
Policy Development for Biodiversity Offsets: A Review of Offset Frameworks	McKenney, B. and Kiesecker, J.	2009	Environmental Management	Brazil
Development by Design in Colombia: Making Mitigation Decisions Consistent with Conservation Outcomes	Saenz, S., Walschburger, T., González, J.C., León, J., McKenney, B. and Kiesecker, J.	2013	PLOS One	Colombia
Offsetting the Impacts of Mining to Achieve No Net Loss of Native Vegetation	Sonter, L.J., Barrett, D.J., and Soares-Filho B.S.	2013	Conservation Biology	Brazil

According to Villarroya, Barros, and Kiesecker (2014) Brazil, Colombia, Mexico, Peru, Argentina, Chile, and Venezuela are the only Latin American countries that have developed some kind of system for implementing biodiversity offsets, with only the first four having specific policies that regulate their implementation. Chile can be added to this list, with a regulatory requirement to offset issued in 2014. Given this lack of scientific research, these countries had heavily relied upon principles, frameworks, and methods developed elsewhere when designing their own. This is a critical factor influencing offset failures, as these strategies should depend on the characteristics of the biodiversity interests being addressed and on the project's context and objectives (DEFRA, 2011).

3. CHAPTER 3: RESEARCH METHODS

3.1. Step 1: Definition of what is an 'appropriate' metric for biodiversity offsets in Latin America according to stakeholders' criteria

Step 1 involved setting and conducting a series of unstructured conversations and discussions with stakeholders involved in the design, implementation, and evaluation of biodiversity offsets across Latin America and worldwide (see Figure 1). These were done to understand their points of view and perspectives on the use of the available metrics to determine ecological equivalences in the context of biodiversity offset strategies. At the same time, stakeholders were asked about the relevant criteria or attributes that these alternative metrics should comply with in order to be considered effective and practical for assessing the balance between offset gains and project impacts. The ultimate objective was to have a clear understanding of the deficiencies of current metrics and to identify the desired attributes of preferable alternatives for the evaluation of biodiversity offsets in Latin America.

This step allowed me to introduce a participatory approach into my research method, an aspect seen as key to the next big wave of innovation in business and society,[9] and described as essential in assessment programs (Buck, Milder, Gavin, & Mukherjee, 2006). According to the ICMM, (2005), it is necessary to involve stakeholders throughout the process of offset identification and design in order to aid transparency, credibility, good governance, and delivery. This will ultimately promote the creation of

[9] As part of the process and guidelines of the Design Thinking Practice (Brown, 2009).

linkages between economic, social, and conservation goals (Lawrence & Robinson, 2014).

Taking the above into consideration, representatives of relevant NGOs, regulating authorities, industries, and environmental management companies (prioritizing those with relevant experience in Latin America) were contacted between September and December of 2014. The aim was to reach out to the full spectrum of stakeholders involved in the biodiversity offset evaluation process, gaining an insight of the research problem and desirable solution's attributes at a multi-level and multi-scale governance context (Table 3). Perspectives from these interviews were synthesized into a set of consensus criteria against which to evaluate the adequacy of offset metrics.

3.2. Step 2: Review and characterization of existing metrics and their implications

This step involved a literature review and analysis process to identify and characterize current metrics for measuring biodiversity values in offset contexts (see Figure 1). This was done following the Systematic Review (SR) process which, in contrast to the classical qualitative review methods, consists of a practical-oriented (Tranfield, Denyer, & Smart, 2003) evidence-based approach. It is highly relevant to summarizing and evaluating extensive literatures (Cook, Mulrow, & Haynes, 1997), which has provided better results in the accuracy of conclusions and in counteracting biases (Mulrow, 1994). The review was done following the three stages, and corresponding phases, of the SR process proposed by Tranfield, Denyer, & Smart (2003; Table 4). A description of the results of each of the three stages of the SR process is presented in Table 5 and detailed below.

Table 3 Stakeholders consulted and the institutions they represent

Type	Institution	Relevance to biodiversity offsets	Stakeholders involved
Non-governmental organization	Colombian conservation NGO	Development of tools for the implementation of biodiversity offsets in Colombia	Ecosystem Services Manager
	Platform of international collaboration between different institutions	Development of best practice in following the mitigation hierarchy to achieve no net loss or a net gain of biodiversity	Senior Policy Advisor
	Peruvian environmental policy NGO	Developed a document about biodiversity offsets and their importance in Peru; developed workshops about biodiversity offsets and auditing in Peru; participated in the development of Peru's Environmental Compensation Law (RM N° 398-2014-MINAM)	Director
Academia	La Molina National Agrarian University (Peru) - Pasture Utilization Laboratory	Designed the method for measuring project impacts and offset gains in Peru, in the context of Peru's Environmental Compensation Law (RM N° 398-2014-MINAM)	Faculty
	Imperial College (London) - Center for Environmental Policy	Development of scientific research and frameworks regarding offsetting strategies in the UK	Faculty
Government	Ministry of the Environment (Peru) - General Direction of Evaluation, Valuation and Financing of Natural Heritage	Responsible of Peru's Environmental Compensation Law (RM N° 398-2014-MINAM) in December, 2014	Economy of Natural Resources Specialist
Private company	Environmental consulting company (Peru)	Experience applying the mitigation hierarchy as part of the management plan of several development projects	Project Manager
	International conservation design and impact company	Worked with executives from leading Chilean natural resource companies that have marine biodiversity impacts to understand their perceptions and willingness to participate in a marine biodiversity offset program under a regulatory and voluntary framework.	Director

Table 4 Stages and phases of the Systematic Review method

Stages	Phases	Description
Stage 1: Planning the review	1.1. Identification of the need of the review	- Iterative process of definition, clarification and refinement of the review objective.
	1.2. Preparation of a proposal for a review	- Should include conducting scoping studies to assess the relevance and size of the literature and to delimit the subject area or topic. - May also include a brief overview of the theoretical, practical and methodological history debates surrounding the field and sub-fields of study.
	1.3. Creation of a review panel	- The review panel should encompass a range of experts in the subjects and include practitioners. - It should help in the decision making process regarding inclusion or exclusion of studies.
	1.4 Arrive to a review question	- Develop a review question based on the existing body of knowledge. - This is considered critical to systematic review as other aspects of the process flow from it.
	1.5 Creation of a review protocol	- The protocol is a plan that helps to protect objectivity by providing explicit descriptions of the steps to be taken.
Stage 2: conducting the review	2.1. Identification of keywords	- The keywords are selected from the literature and discussions with the review panel.
	2.2. Information search/selection of studies	- The searches should be conducted in academic journals, unpublished studies, conferences, internet and interviews. - The output of the information search is a full listing of articles and papers on which the review will be based.
	2.3.Development of data extraction matrices	- Development of data extraction forms/matrices. - These should be directly linked to the review questions.
	2.4. Conduct the review of selected literature and data extraction.	- Data review and extraction onto the created matrices.
	2.5. Develop synthesis	- Involves answering the review questions.
Stage 3: reporting and dissemination	3.1. Develop the report and recommendations	- The results should be presented in a user-friendly format, improving the translation of research evidence into practice.
	3.2. Disseminate the report	- Share the report with the review panel, developing context sensitive science.

Source: Tranfield, Denyer, & Smart, 2003.

Table 5 Results of the Systematic Review Process

Stage	Phase	Result
Stage 1: Planning the review	1.1	This was done as part of the literature review of Step 1.
	1.2	This was done as part of the literature review of Step 1.
	1.3	Meetings and tele-conferences with experts in the topic from: 1. International conservation design and impact company 2. Environmental consulting company (Peru) 3. Cornell University
	1.4	Design of the specific questions: 1. What are the different available metrics for measuring biodiversity values in the context of offsetting strategies and how are they characterized? 2. What are the best currently existing metrics for measuring biodiversity values in Latin America in the context of offsetting strategies (according to standardized frameworks and stakeholder's criteria)? 3. For what biodiversity offset project scenario is each metric more suitable?
	1.5	Due to time limitation, there was not a formal protocol for the review process.
Stage 2: conducting the review	2.1	The following keywords were considered: biodiversity offset*, compensatory mitigation, habitat offset*, environmental offset*, conservation bank*, habitat bank*, offset metric*, offset method*, offset gains*.
	2.2	Four main articles containing offset metric reviews were chosen: McKenney & Kiesecker, 2010; Bull, Milner-Gulland, Suttle, & Singh, 2001; Quétier & Lavorel, 2011; Virah-Sawmy, Ebeling, & Taplin, 2014. Additional literature was also reviewed to determine the need of including additional metrics; those metrics that required the implementation of specific indicators significantly different from the ones already being considered were included.
	2.3	Extraction Matrix N°1: Comparison of core principles of the selected metrics for assessing biodiversity values. Extraction Matrix N°2: Characterization of biodiversity offset metrics according to: 1. Indicator desirable properties (Munn, 1988; Noss, 1990). 2. Attributes of suitable forms of metrics (BBOP, 2012). 4. Attributes of a potential 'best' metric, according to the results of Step 1.
	2.4	The data extraction matrices were completed for a total of 13 different metrics using the literature compiled as part of phase 2.2.
	2.5	Use of the extraction matrices, and development of other result products with the information provided, to answer the review questions.
Stage 3: reporting and dissemination	3.1.	Involved developing and integrating the SR final products. This was done as part of the last step of my research (Step 5).
	3.2	Products were created based on a continuous feedback process with experts in the topic (the review panel). The actual dissemination of the results was done as part of the last step of the research (Step 5).

Source: Tranfield, Denyer, & Smart, 2003.

3.2.1. Stage 1: Planning the review

This stage included the creation of a review panel conformed by a range of experts on the topic, who agreed to help direct the review process through regular meetings and consultations. For this purpose, meetings and tele-conferences were set up with experts in the theory and practice of biodiversity offsets (Table 6).[10] The review panel provided continuous feedback throughout the SR process and the development of my research.

Table 6 Stakeholders who formed the review panel

Institution	Type	Relevance to biodiversity offsets	Stakeholders involved
International conservation design and impact company	Private company (international)	Worked with executives from leading Chilean natural resource companies that have marine biodiversity impacts to understand their perceptions and willingness to participate in a marine biodiversity offset program under a regulatory and voluntary framework.	Director
Environmental consulting company	Private company (Peru)	Experience applying the mitigation hierarchy as part of the management plan of several development projects	Project manager
Cornell University	Academia	Experts with broad experience in international conservation and the development of biodiversity planning and management projects in Latin America	Faculty

Another important phase of this first stage involved developing the review questions. These are considered critical to the SR process as other aspects of the approach flow from them. As indicated in Table 5, the review questions included:

- What are the different available metrics for measuring biodiversity values in the context of offsetting strategies and how are they characterized?

[10] Most of the experts considered include the stakeholders consulted during Step 1 of my research (see Subsection 3.1, Table 3).

- What are the best currently existing metrics for measuring biodiversity values in Latin America in the context of offsetting strategies (according to standardized frameworks and stakeholders' criteria)?
- For what biodiversity offset project scenario is each metric more suitable (if any)?

Each one of the indicated questions was answered with the results obtained from the SR process.

3.2.2. Stage 2: Conducting the review

The second stage of the SR process involved conducting the actual review. It started with the identification of keywords and search terms, which were built from the literature and discussions with the review panel. The following keywords were considered: biodiversity offset*, compensatory mitigation, habitat offset*, environmental offset*, conservation bank*, habitat bank*, offset metric*, offset method*, offset gains*, offset benefits*, offset currency*; the asterisks indicate that articles containing derivations of the main words were also included (see Table 5).

The information search was then conducted to identify the different existing metrics for measuring biodiversity values. Academic journals, unpublished studies, conferences, interviews, and electronic papers were considered for this purpose. After reviewing all the information available, the set of existing metrics for evaluating biodiversity offsets, subject matter for this analysis, was mainly taken from four recent reviews: Bull, Milner-

Gulland, Suttle, and Singh (2014); McKenney and Kiesecker (2010); Quétier and Lavorel (2011); and Virah-Sawmy, Ebeling, and Taplin (2014).

It is important to mention that some of the biodiversity offset metrics included in these reviews were not taken into account for the present assessment due to different specific reasons. The Natura 2000 framework (centerpiece of the European Union nature and biodiversity policy), assessed by McKenney and Kiesecker (2010) and Quétier and Lavorel (2011), was not considered as it does not advocate any specific calculation for measuring biodiversity values (BBOP, 2009). The same in the case of the Habitat and Resource Equivalency Analysis (HEA and REA), characterized by Quétier and Lavorel (2011), which does not include a specific accounting system for measuring losses and gains (BBOP, 2009). In the case of the Brazilian industrial and forest offset regulations,[11] addressed by McKenney and Kiesecker (2010), these were excluded as their future is unclear (Madsen, Carroll, Kandy, & Bennett, 2011), and they arguably do not fulfill criteria for offset policies. Likewise, the Canadian Fish Habitat Framework, addressed by Bull, Milner-Gulland, Suttle, and Singh (2014) was not considered as this research is only focused on terrestrial ecosystems. Finally, France's offset ratios method was also excluded, as it is based on the American compensation bank mechanism (Morandeau & Vilaysack, 2012), which is already being addressed.

The set of seven metrics selected from the reviews was complemented with six additional accounting methods that involve the use of significantly different approaches,

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[11] Federal Law 9985, Decree 4340, and Federal Law 4771, Provisional Measures 2166/67, respectively.

parameters, and/or indicators. Based on the metrics' objectives, applicability as accounting systems, focus on terrestrial ecosystems, and level of uniqueness , a final set of 13 different biodiversity offset metrics was selected for the present assessment (Table 7).

Table 7 Biodiversity offset metrics considered for the present assessment

Biodiversity offset metric	Acronym	Established by
Habitat Hectares	HH	Victorian Department of Natural Resources and Environment (NRE) - State of Victoria, Australia.
Units of Global Distribution	UD	Rio Tinto (mining company)
Uniform Mitigation Assessment Method	UMAM	Department of Environmental Protection - Florida, US
Biodiversity Significance Index*	BSI	New South Wales Department of Natural Resources – State of New South Wales, Australia
Conservation Significance Index	CSI	Virah-Sawmy, Ebeling, and Taplin (independent researchers)
Offset ratio - US Wetland Banking	-	US Federal Government (through the Clean Water Act)
Offset ratio - US Conservation Banking	-	US Federal Government (through the Endangered Species Act)
Metric for Biodiversity offsetting pilots in England, UK	DEFRA metric	Department for Environment, Food and Rural Affairs – England, UK.
Module Assessment Method	MAM	Federal Office for the Environment (FOEN) – Switzerland.
Biotope Valuation - Ausgleich procedure	BV	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety – Germany. .
Habitat Units	HU	Fish and Wildlife Service Federal Agency, US.
Significant Environmental Benefit	SEB	Department of Water, Land and Biodiversity Conservation – State of South Australia, Australia.
Offset ratios	-	Department of Environmental Affairs and Development Planning (DEADP) – Province of the Western Cape, South Africa.

(*) Indicator within the Biodiversity Benefits Index (BBI)

I then characterized the selected set of biodiversity offset metrics according to two sets of parameters: attributes of biodiversity (composition, structure, and function), and biodiversity levels of organization targeted (landscape, ecosystem, species, genetic); and two sets of characteristics: indicator desirable properties (Munn, 1988; Noss, 1990), and attributes of suitable forms of metrics (BBOP, 2012). These parameters and characteristics were systematized into two data extraction matrices based on the information obtained from the literature review.

- **Extraction Matrix N°1:** Comparison of core principles of the selected metrics for assessing biodiversity values. This matrix presents the core principles and characteristics of each metric, including their objectives, formula, description, offsetting target, number of indicators, benchmark consideration, and inclusion of a landscape context. It also characterizes each metric according to Noss's (1990) composition-structure-function attributes of biodiversity and their landscape-ecosystem-species-genetic levels of organization framework, for selecting biodiversity indicators.

- **Extraction Matrix N°2**: Characterization of offset metrics according to:
    - Indicator desirable properties (Munn, 1988; Noss, 1990):
        - Geographic applicability (Latin American context)
        - Sensitivity
        - Capability of providing continuous assessment over a wide range of stresses
        - Cost and time effectiveness and practicality
        - Ability to differentiate between natural and anthropogenic-induced cycles or trends
        - Relevancy to ecologically significant phenomena

- Attributes of suitable forms of metrics (BBOP, 2012):
    - They capture the type, amount, and condition or quality of the biodiversity that is being lost or gained.
    - They adequately quantify the losses and gains at the species, communities and assemblages, habitats, and ecosystem levels within the specific context of the project.
    - They enable the calculation of residual losses and gains of use and cultural values of biodiversity.
    - Surrogate metrics are used with an understanding of the relationship between changes in the surrogate value and changes in the value of the underlying biodiversity of conservation concern, and evidence should be provided supporting this relationship.
    - They should include context-dependent information about conservation status, vulnerability, or irreplaceability of the biodiversity component(s).
    - Assumptions and rationale for selection of metrics are clearly documented.
- Attributes of a potential 'best' metric for assessing the balance between offset gains and project impacts in Latin America, according to the results obtained in Step 1 of my research (see Subsection 3.1).

In the case of the first two frameworks used to characterize offset metrics as part of Extraction Matrix N°2, indicator desirable properties (Munn, 1988; Noss, 1990) and attributes of suitable forms of metrics (BBOP, 2012), each metric was evaluated against each of the six corresponding sub-criteria per framework. A numerical score was assigned each time, indicating how well the metric fits with the sub-criteria being assessed. A '1' to '5' scale was used, as indicated in Table 8. The sub-scores obtained for each metric were added and the final value divided by the maximum possible score (60). A total score (TS_1) was obtained.

Table 8 Scale used to characterize correspondence of metrics to the sub-criteria of the frameworks considered

Score	Description
1	The metric cannot be characterized at all by the sub-criteria being assessed
2	The sub-criteria does not describe the metric
3	The sub-criteria describes the metric but only to some extent
4	The sub-criteria describes the metric
5	The sub-criteria fully describes the metric
TS_1	$\frac{\sum_{i=1}^{12} subcriteria_i}{60}$

Key:
TS_1 = Total Score that characterizes the correspondence of metrics to the sub-criteria of the frameworks considered; i = score obtained per sub-criteria

Regarding the stakeholders' criteria, as in the previous process, each metric was evaluated against each of the identified attributes of a potential 'best' metric. However, in this case, as most of the attributes respond to a yes or no question, a '0' or '1' score was selected; '1' indicates that the metric can be described by the corresponding attribute, and '0' that the metric cannot be characterized at all by the attribute being assessed. The values were added and a total score (TS_2) was obtained. Because of the importance of considering stakeholders' perspectives in the evaluation process, the TS_2 score acts as a weighting factor, that is, it is multiplied by TS_1 to obtain a final score (FS; Equation 1).

Equation 1 Final score for determining the correspondence between each metric, the frameworks considered, and stakeholders' attributes of 'best' metrics

$$FS = (TS_1) * (TS_2) \ = \left(\frac{\sum_{i=1}^{12} subcriteria_i}{60} \right) * (\sum_{j=1}^{6} subcriteria_j)$$

Where:
FS = Final Score
TS_1 = Total Score that characterizes the correspondence of metrics to the sub-criteria of the frameworks considered
TS_2 = Total Score that characterizes the correspondence of metrics to the attributes of a potential 'best' metric, identified by stakeholders.
i = score obtained per sub-criteria of the frameworks considered
j = score obtained per attribute of a potential 'best' metric, identified by stakeholders

High final scores indicate a high level of correspondence between the metric, the frameworks considered for assessing indicator quality (in a Latin America context), and stakeholders' criteria; low final sores indicate poor levels of correspondence. Although the metric with the highest score is the one that better meets frameworks' and stakeholders' considerations for measuring equivalences, the final metric selection should always be case-dependent, addressing the context and objectives of the project being concerned.

Finally, the last phase of this second stage of the SR process involved using the extraction matrices, and developing other result products with the information provided to answer each of the review questions. A decision tree for determining the 'best fit' metric was developed, aimed at helping stakeholders select the most adequate metric for their specific biodiversity offset project. This decision tree presents, in a practical and effective way, a suite of currently existing metric options for assessing equivalencies, while at the same time, addresses the suitability of each choice under different project contexts.

3.2.3. Stage 3: Reporting and dissemination

The third and final stage of the SR process involved developing and integrating the final results obtained. This was done as part of the fifth and last step of my research method (Step 5, Subsection 3.5), where the different products obtained were integrated in a structured step-by-step decision making tool, which was disseminated among stakeholders to aid in the evaluation of biodiversity offset success in Latin America.

3.3. Step 3: Development of a logic model for assessing offset performance over time and across space

Evaluating projects, especially conservation ones, can be very challenging (Margoluis, Stem, Salafsky, & Brown, 2009). Conservation projects are inherently complex, both in detail and in dynamics and the required evidence to demonstrate their success is usually absent. The lack of clear and measurable goals and objectives, and the unwillingness of involved stakeholders to devote sufficient human and financial resources to evaluation and monitoring activities are also important limitations involved (Margoluis, Stem, Salafsky, & Brown, 2009).

Given this situation, historically, many conservation organizations have adopted a very simplistic formula for conducting conservation project evaluations: define indicators, collect data, analyze data, and write up results (Margoluis, Stem, Salafsky, & Brown, 2009). “At best, conservation managers have used biological indicators to demonstrate the extent to which a project has been successful, but they have rarely analyzed these measurements in the context of project interventions or the intermediate results they intended to achieve” (Margoluis, Stem, Salafsky, & Brown, 2008, p. 138). Nevertheless, the demand by different institutions (e.g., regulators and donors) for evaluations grows, which has resulted in the conduction of fairly unsystematic and unfounded project evaluation processes, with outcomes that fail to achieve the objective of the process itself.

Considering this situation, how can evaluators best frame a project for an objective evaluation? How can stakeholders develop interventions that can be adequately evaluated in the future? How can they determine the best indicators to measure project success? In the context of biodiversity offset strategies in Latin America, I propose the Offset Performance Logic Model (OPLM) as a powerful evaluation and decision making tool to address these questions. The model was developed using the results obtained in Steps 1 and 2 of my research (see Figure 1). These first results act as the first steps of a continuous and structured process for determining ecological equivalence, and provide the inputs to the OPLM, which assess the strategy’s success in a systematic and adaptive way. It is important to highlight that the use of the OPLM does not substitute the use of biodiversity offset metrics. It represents an additional further step, complimentary to the use of existing metrics for valuing equivalences, aimed at providing certainty in the achievement of no net loss of biosiversity in a landscape context.

Currently, logic models are the most common form of theory of change representation used for planning and evaluation (Margoluis, Stem, Salafsky, & Brown, 2009). A logic model is a “systematic and visual way to present and share your understanding of the relationships among the resources you have to operate your program, the activities you plan, and the changes or results you hope to achieve” (Kellogg Foundation, 2004, p. 1). It uses words and/or shapes to describe the sequence of activities proposed to generate change and how these activities are linked to the expected results. These generally illustrate the resources managers will invest (i.e., inputs) to implement strategies that are designed to achieve certain desired results (i.e., outputs, outcomes, and impacts).

In the OPLM, offset performance is assessed in terms of the ecological equivalence between the offset and impact sites over time and across space. In this sense, after determining the offset requirements for a particular project using the most suitable available metric[12] (Products P1 through P2c serve this purpose),[13] the OPLM could be used for the following two applications.

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[12] As indicated before, the OPLM represents an additional further step, complimentary to the use of existing metrics for valuing equivalences; it does not act as a stand-alone tool, nor replaces the use of biodiversity offset metrics.
[13] Which will ultimately depend on the project’s context and conservation objectives.

- **Application 1:** Selection of the most appropriate offset site from a set of potential offset areas (i.e., analysis across space).
- **Application 2:** monitoring of the development of a specific established offset area (i.e., analysis over time).

The model was developed following the steps of the modelling process proposed by Sterman (2000). Each of the steps followed for the two possible applications of the OPLM, which depend on the specific objective to be achieved, are presented in Table 9. The first and second stages of the modelling process, referred to problem articulation and dynamic hypothesis, were developed considering the two applications of the OPLM (Table 9). The results of these two stages are detailed in Subsection 4.3.1. In the case of the third stage, formulation of a simulation model, The Nature Conservancy's (TNC) 5-S Framework for strategic conservation planning and the assessment of measures of conservation success was considered (TNC, 2003; Figure 2). The process was focused on the first 'S' of this framework (Systems), which includes the development of the following phases.

- **Target identification:** identification of the offsetting targets that the management strategy will focus on (i.e., species, communities, ecological systems).
- **Target characterization:** characterization of the selected targets according to specific indicators.

Table 9 Stages of the modeling process followed

Stage	Application 1	Application 2
1. Problem articulation		
Theme selection	Problem: Absence of systematic tool for selecting an offset area that provides the offset requirements by considering its location in the landscape. Question: How to select the best offset area alternative in relation to its location in the landscape?	Problem: Absence of systematic tool for assessing if an offset area is compensating what has been lost over time, in relation to the location of both areas in the landscape. Question: How to assess if the offset area is adequately compensating what has been lost over time, in relation to the location of both areas in the landscape?
Key variables	1. Set of potential offset areas 2. Impact area (and the corresponding offset requirements) 3. Landscape considered/scale	1. Offset area 2. Impact area (and the corresponding offset requirements) 3. Landscape considered/scale
Time horizon	Not applicable	Not applicable
Reference modes	Not applicable	Not applicable
2. Dynamic Hypothesis		
Initial Hypothesis generation	Existing metrics do not (appropriately) consider the landscape context when determining offset requirements and thus selecting the most appropriate offset site	Existing metrics do not provide a framework to monitor the performance/evolution of an offset area over time within a landscape context.
Endogenous focus	Selected offset area is not necessarily equivalent to impact area in terms of the landscape context/dynamics its within	Landscapes are susceptible to disturbances, and this might affect the viability of biodiversity at the offset site over time.
Mapping	See Subsection 4.3.1	
3. Formulation of a simulation model		
Structure, decision rules	The model was developed following TNC's 5-S framework for strategic conservation planning and the assessment of measures of conservation success (TNC, 2003). Specifically, it focuses on the first 'S' of this framework (Systems), which includes the development of the following phases: 1. Identification of offsetting targets 2. Characterization of offsetting targets 3. Scoring of offsetting target 4. Calculation of Offset Performance Value	
Parameters, initial conditions, relationships		
Test for consistency		
4. Testing		
This was developed as part of Step 4 of my research. This step tests, analyzes and compares how different metrics behave when accounting for losses and gains for specific projects.		
5. Policy design and evaluation		
This was developed as part of Step 5 of my research. The model was integrated in a structured step-by-step tool to aid stakeholders in the implementation of biodiversity offsets in Latin America and the evaluation of their success.		

Source: Sterman, 2000

- **Target scoring:** scoring of the focal offsetting targets in relation to the obtained results. This will be the basis for determining the Offset Performance Value (see Subsection 4.3.1.3), and thus assessing how well the offset area is performing in relation to the impact site over time (monitoring purposes) and/or across space (selection between different potential offset areas).

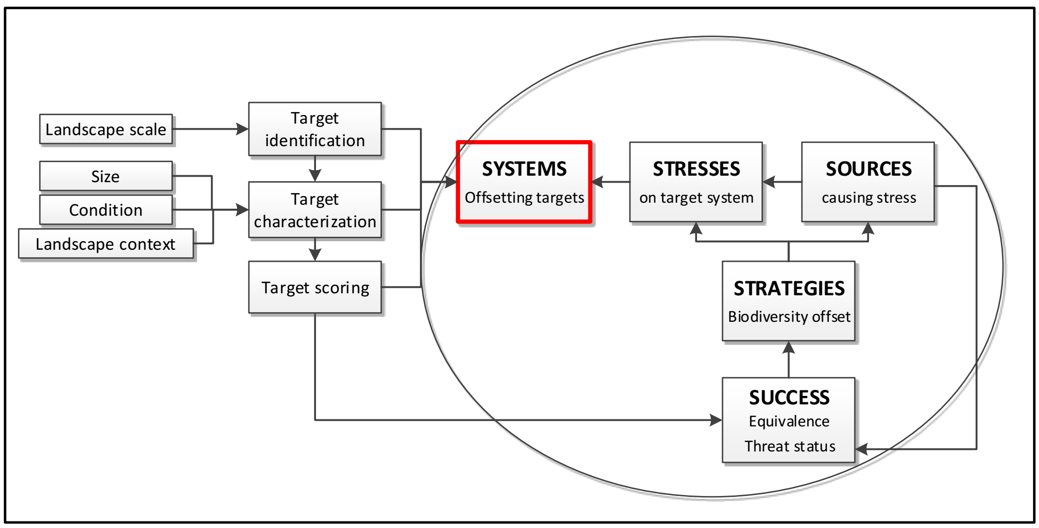

Figure 2 TNC's 5-S Framework logic and its application to the development of the Offset Performance Logic Model

Source: TNC, 2003

In the case of target characterization, offsetting targets are characterized considering the size-condition-landscape context criteria for assessing the characteristics of conservation targets according to TNC (2003), and as indicated in Figure 2.

- **Size:** measure of the target's area or abundance. For ecological systems, size refers to the patch size or geographic coverage.
- **Condition:** integrated measure of the composition, structure, and biotic interactions (e.g., competition, predation, diseases, etc.) of the target. The

characterization of this criterion is framed according to Noss's (1990) attributes of biodiversity: composition-structure-function. Under this framework, biodiversity can be considered as an output of ecosystem integrity, where anthropogenic impacts can reduce such integrity and thus threaten an area's ability to support biodiversity.

- **Landscape context:** integrated measure of two factors; e.g., dominant environmental regimes and processes that establish and maintain the target occurrence, including many kinds of disturbance (attribute of biodiversity: function), and connectivity (attribute of biodiversity: structure).

Each of the mentioned criterion is characterized by the use of a specific set of indicators.[14] Which indicators are required to truly evaluate the impact and characterize each criterion is a key question that often fails to be properly addressed. Before selecting them, it is important to clearly establish and define the objectives that these are going to measure, as both represent (objectives and indicators) the basis for creating and for evaluating management alternatives (Gregory et al., 2012). The corresponding objectives are presented disaggregated in the objective hierarchy illustrated in Figure 3. The indicators selected to characterize the offsetting target need to be able to measure the means objectives and quantify the performance criteria outlined in the figure.

[14] Units of information measured over time that document changes in a specific condition (Margoluis, Stem, Salafsky, & Brown, 2009)

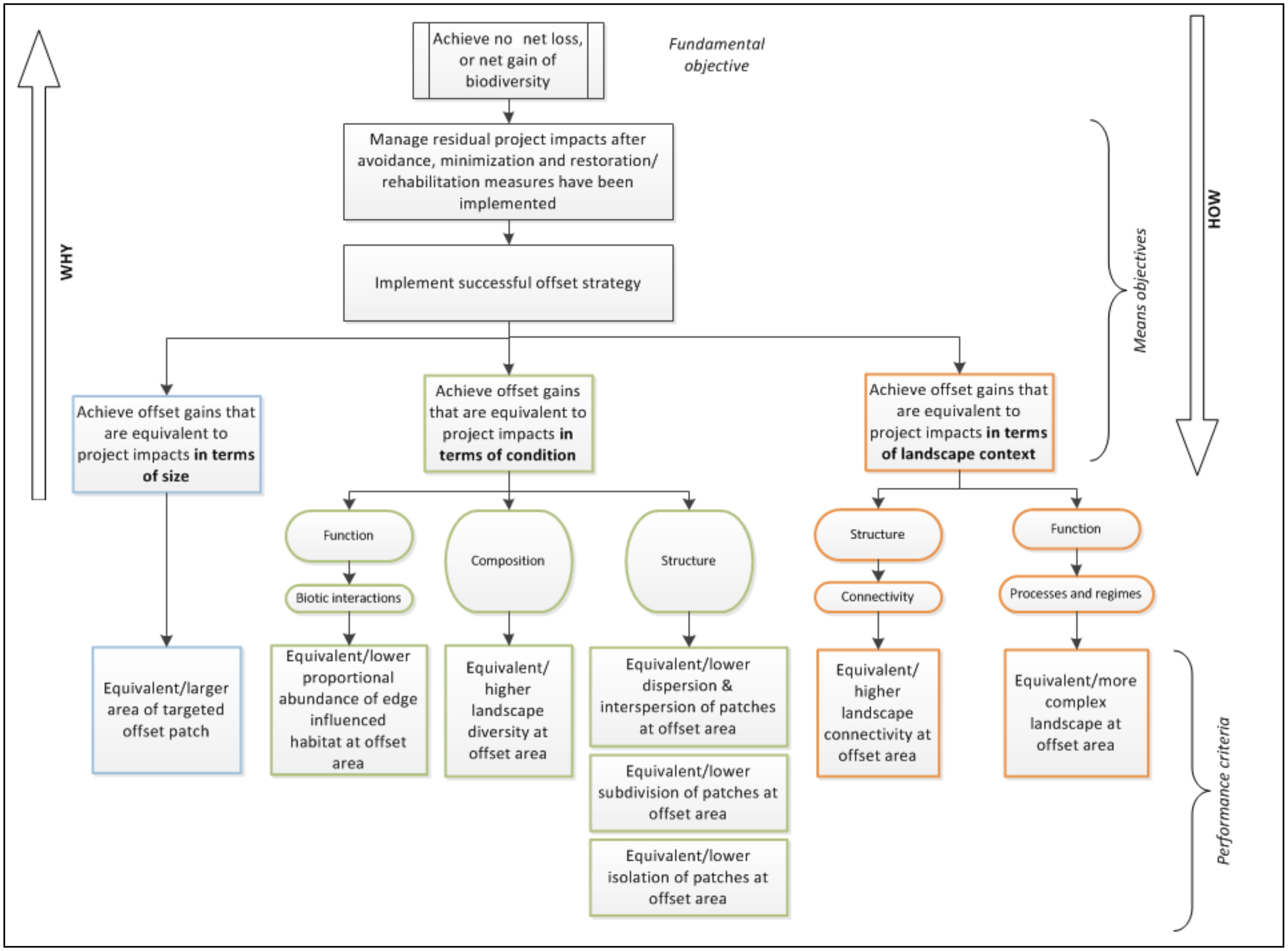

Figure 3 Objective hierarchy

The selected indicators correspond to landscape metrics, defined as algorithms that quantify specific characteristics of a categorical map, corresponding to either its composition or spatial configuration. This step represented a key phase of the process, as determining what indicators of landscape performance to use is vital to producing an assessment that will tell stakeholders whether or not their landscape is moving in the right direction with respect to their goals (Buck, Milder, Gavin, & Mukherjee, 2006).

Landscape indicators exist at the patch, class (patch type), and landscape level. Patches are the basic building blocks of categorical patch mosaics and, as such, most metrics derive from the spatial character and distribution of the patches themselves. Class metrics represent the spatial distribution and pattern within a landscape of a single patch type; whereas landscape metrics represent the spatial pattern of the entire landscape mosaic, considering all patch types simultaneously. Many of the class and landscape metrics are computed from patch and class statistics by summing or averaging over all patches or classes. The proposed indicators correspond to the three different levels of metrics, depending on the criterion and attribute of biodiversity being assessed.

Indicators were finally selected based on a literature review of their advantages, disadvantages, properties, and applications, as well as on the information about the landscape they provide and how useful is this information for quantifying the performance criteria indicated in Figure 3. Moreover, they cover the five properties of good attributes outlined by Keeney and Gregory (2005): unambiguous, direct, operational, comprehensive, and understandable.

The calculation of the selected indicators is done using a spatial pattern analysis computer software program (e.g., FRAGSTATS[15] for ArcGIS). The data input for this analysis consists on land cover maps, portrayed as a mosaic of categorical patches. Such maps can be produced using multispectral satellite images through the supervised classification method (Lillesand, Kiefer, & Chipman, 2004).

Grain and extent, together, determine the scale at which a landscape is described in a study (Graves, 2010) and, in this case, the results of the landscape metrics considered (especially in the case of the metrics at the class and landscape level). Grain describes the size of the smallest homogeneous unit of study (cell or minimum polygon size) and determines the resolution at which a landscape is analyzed (Graves, 2010), while the extent refers to the area included within the landscape boundary (study area). According to a study developed by Wu, Shen, Sun, and Tueller (2002) on the effects of changing scale on landscape metrics, these can be classified into three different categories according to their scaling behavior: type I, which show predictable responses with changing scale; type II, which exhibit staircase-like responses; and type III, which behave erratically in response to changing scale. In all cases, the metrics' results were affected by a change in the grain and extent of the analysis, and only metrics in the first group,

[15] This is a computer software program designed to compute a wide variety of landscape metrics for categorical map patterns using land cover raster images (McGarigal & Marks, 1995).

those with predictable behavior, could be extrapolated or interpolated across scales.

Both aspects, which are dictated by the scale of the imagery used, should be determined depending on the particular project being addressed; “otherwise the measured landscape patterns will have little meaning and there is a good chance of reaching erroneous conclusions” (Botequilha Leitão, Miller, Ahern, & McGarigal, 2006, p. 56.). Given that the grain sets the minimum resolution of investigation, in most cases it is much safer to choose a finer grain than is believed to be important (McGarigal, n.d.).

Finally, going back to the different stages of the modeling process (See Table 9), in the case of the testing stage this was completed as part of Step 4 of my research (Subsection 4.4). It involved analyzing and comparing how different metrics behave when accounting for losses and gains for specific projects. A specific biodiversity offset case study (BOCS) was selected, for which potential offset requirements were calculated. Regarding the last stage of the modeling process (policy design and evaluation), this is included within the fifth and last step of my research (Subsection 4.5). The different developed products (including the OPLM) were integrated in a structured step-by-step tool to aid stakeholders in the implementation of biodiversity offsets in Latin America and the evaluation of their successes over time.[16]

3.4. Step 4: Assessing existing metrics and the developed model against a case study

The objective of this step was to test, analyze, and compare how different biodiversity offset metrics behave when accounting for losses and gains for specific projects, and how well the results these provide can be fed into the developed Offset Performance Logic Model (OPLM). Some of the questions that were answered through this step include: Do different metrics produce equivalent results? Are offset gain calculations dependent on the type of metric used? By how much? Are such calculations consistent with the results provided by the OPLM?

A mining project located in the highlands of Peru[17] was selected as a biodiversity offset case study (BOCS), for which potential offset requirements were calculated for compensating the loss of a particular ecosystem. This project was chosen as the BOCS primarily because of the availability of the information required for the different analyses conducted, but also considering the high severity of the predicted impacts (project footprint of approximately 2,000 ha), and the high

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[16] The use of the OPLM is complementary to the use of the previous products obtained in my research (including the matrixes comparing and characterizing biodiversity offset metrics, and the decision tree for choosing the 'best fit' metric).

[17] Construction was halted in 2011. The development and completion of the project is not anticipated for the foreseeable future (Jamasmie, 2016).

biodiversity values at stake (more than 100 ha of peatlands within the area of influence), (Knight Piésold, 2010).

The selection of metrics was made based on the products presented as part of Step 2 of my research method: matrix characterizing available biodiversity offset metrics according to established frameworks and stakeholders' criteria (Product P2b, see Figure 1) and the decision tree for choosing the 'best fit' existing metric (Product P2c, see Figure 1). Once the offset requirements were determined using the selected metrics, and potential offset areas analyzed in terms of their capacity to offset the corresponding impacts, the OPLM (Product P3, see Figure 1) was used to determine the appropriateness of the offset sites considered in terms of their location within the landscape.

3.4.1. Description of the biodiversity offset case study analyzed

The mining project of the BOCS analyzed is located in Peru's northern highlands, between 3,700 and 4,262 m of altitude, 75 km northeast of the city of Cajamarca (Figure 4). It has a total projected footprint of approximately 2,000 ha, comprising two main open pits, waste rock disposal dumps, topsoil stockpiles, mineral processing facilities, water reservoirs, tailings storage facility, among other infrastructure (Knight Piésold, 2010). As presented in Table 10, 89% of the project's area is comprised by scrubland, followed by 5% of agricultural land and peatland areas.

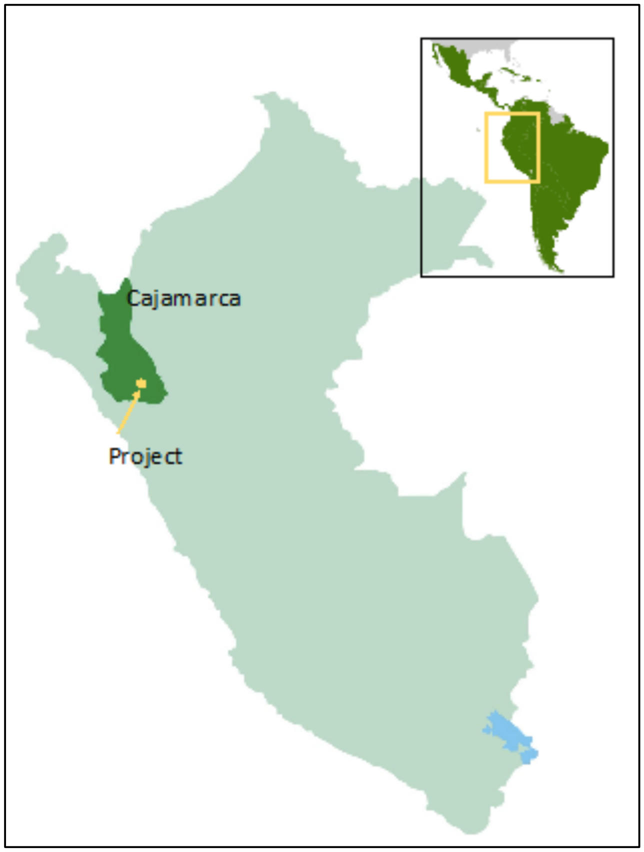

Figure 4 Location of the biodiversity offset case study in northern Peru

Table 10 Vegetation formations affected by the project footprint

Vegetation formation	Area occupied by the project footprint	
	Ha	%
Scrubland	1,720.6	89
Bushland	24.3	1
Peatland	102.7	5
Agricultural land	91.4	5
Riparian vegetation	0.1	0
Others (rocky areas, water courses, etc.)	28.2	1
Total	1,939.1	100

Source: Knight Piésold, 2010

3.4.1.1. Biogeographical features of the biodiversity offset case study area

The BOCS area comprises five different sub-basins (approximately 29,490 ha in total): Jadibamba river, Toromacho Stream, Chugurmayo Stream, Chailhuagón Rover, and Alto Chirimayo Stream sub-basins (Figure 5). These sub-basins were identified and delimited in the Project's Environmental Impact Assessment (EIA), considering factors such as altitude, hydrologic network, among others (Knight Piésold, 2010). Metrics at the landscape and class level were calculated considering these sub-basins as the total analysis areas.

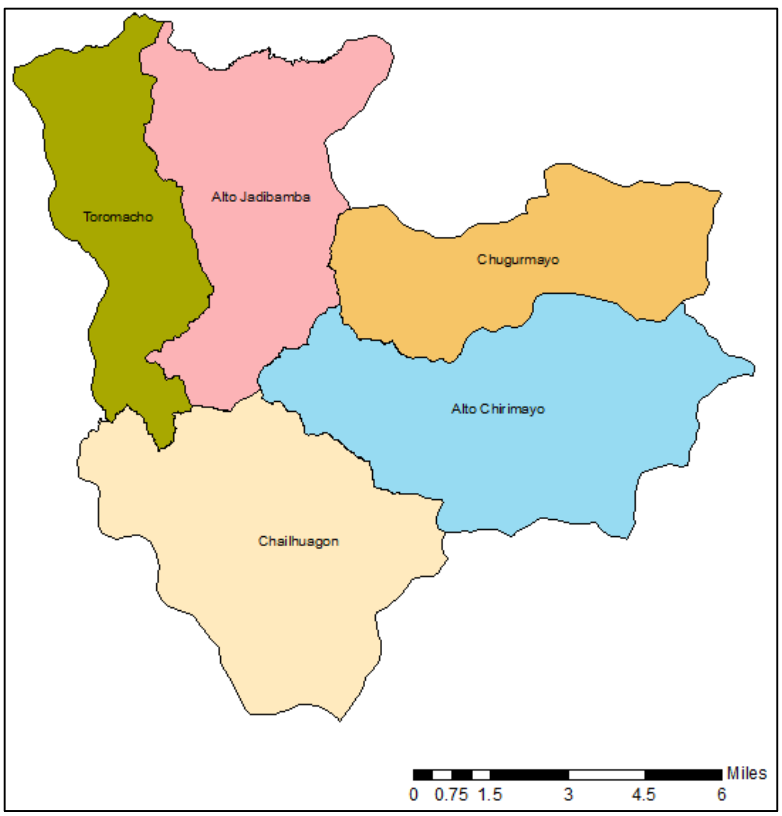

Figure 5 Sub-basins of the biodiversity offset case study area

For the purpose of this assessment, considering the ecological and hydrological importance of peatlands, the potential offsetting strategy targets the compensation of this vegetation type. In general, the peatlands of the BOCS area are dominated by stunted vegetation forming tightly-packed cushions, compact carpets of vegetation close to water pools, presenting four different types of vegetation: cushion-like, reed beds, bryophyte and lichens, and low grasses. According to their water source chemistry and landform, the peatlands being assessed are classified as being slope peatlands, with water highly acidic (Knight Piésold, 2010). This specific type of peatlands presents the following main vegetation communities (Knight Piésold, 2010).

- ***Carex crinalis - Sphagnum pylaesii***: This community occurred in and around pools at the larger acid wetlands. It may support *Carex crinalis* in the pools, among others. *Sphagnum pylaesii* may occur submerged.
- ***Werneria nubigena – Campylopus* spp**: This is one of the most distinctive communities in many wetlands because of the striking leaves and flowers of *Werneria nubigena.*
- ***Sphagnum magellanicum – Cladina confusa - Loricaria lycopodinea***: This is the most common and distinctive community in acidic wetlands in the region. It is dominated by several species of *Sphagnum* mosses, mainly *S. magellanicum*, as well as lichens, including *Cladina confusa, C. arbuscula,* and *C. aggregata. Loricaria lycopodinea* is the most characteristic vascular plant in this community, dominated by non-vascular plants.

- ***Cortaderia hapalotricha - Cortaderia sericantha:*** Stands dominated by these two species of *Cortaderia,* characteristic of most wetlands with acid soils. This community occurred on higher areas between pools that had deeper water tables and were never flooded.
- ***Calamagrostis tarmensis - Campylopus cucullatifolius***: Bunch grass communities dominated by *Calamagrostis tarmensis* and other species of *Calamagrostis*, characteristic mainly of wetlands with acid soils.

No endemic or threatened flora species that are specific to only this vegetation formation have been reported within the BOCS area. However, individuals of *Baccharis genistelloides*, categorized as Near Threatened by Peruvian legislation, and of *Chuquiraga weberbaueri,* endemic of Peru, have been reported in the peatlands of the BOCS area (Knight Piésold, 2010). The same in the case of fauna species; two bird species, one endemic and one categorized as Near Threatened, and one endemic reptile, have been reported on the peatlands of the BOCS area, although these are not necessarily specific of such vegetation formation (Table 11).

Table 11 Endemic and threatened species of the peatlands of the biodiversity offset case study

Taxonomy	Species	National status
Plant	*Baccharis genistelloides*	NT
	Chuquiraga weberbaueri	End
Reptile	*Petracola ventrimaculatus*	End; VU
Birds	*Podiceps occipitalis**	NT
	*Metallura phoebe**	End

(*) Species categorized as Least Concern by the International Union for the Conservation of Nature (IUCN) Red List.
Key:
Status: End = Endemic; NT = Near Threatened; VU = Vulnerable.
Source: Knight Piésold, 2010

3.4.1.2. Impact and benchmark areas

The assessment focuses on offsetting the impacts on the largest peatland patch compromised by the project footprint (23 ha) located in the Alto Chirimayo sub-basin, which would be removed due to the implementation of the pit (Figure 6). The benchmark area,[18] located in the Chugurmayo sub-basin, was selected considering peatland patches of the same type as the offsetting target (slope peatlands with highly acidic pH water), that do not present signs of fragility, productivity and overgrazing, according to the information provided in the project's EIA (Figure 6).

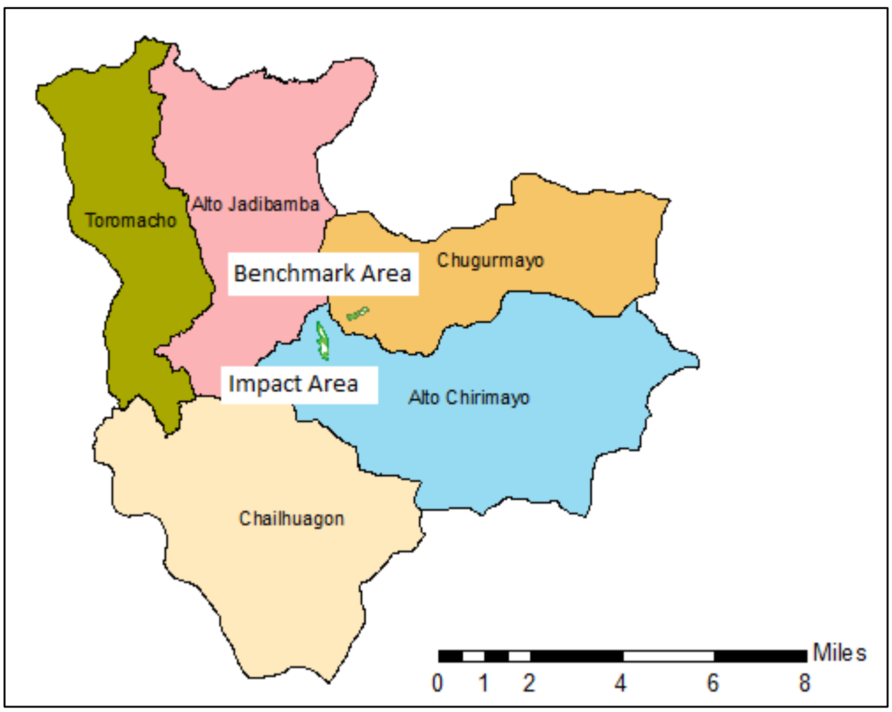

Figure 6 Impact and benchmark areas of the biodiversity offset case study

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[18] The benchmark area presents the average characteristics of a mature and apparently undisturbed patch of the same vegetation type as the one being assessed. Its purpose is to act as a reference of the optimum state of the habitat type being assessed, measuring losses and gains against it. Its use corresponds to one of the attributes of a potential 'best' metric for assessing the balance between offset gains and project impacts, according to stakeholder's criteria (see Subsection 4.1)

3.4.1.3. Potential offset areas

Five different peatland sites within the BOCS area were selected to conform a portfolio of potential offset areas, each of which was analyzed to determine if, and up to what point, it can be used to offset the impacts on the selected impact site (Figure 7). The selection was done considering the availability of biological information per site, required to calculate the offset metrics considered (e.g., species richness, coverage, etc.).

- Offset A – Chailhuagon sub-basin
- Offset B – Alto Jadibamba sub-basin
- Offset C – Toromacho sub-basin
- Offset D – Alto Chirimayo sub-basin
- Offset E – Chugurmayo sub-basin[19]

3.5. Step 5: Integration of results into a validated decision making tool

Finally, all the obtained results (Steps 1 through 4) were integrated in a structured step-by-step decision making tool to aid stakeholders in the implementation and evaluation of biodiversity offset success in Latin America. This tool was disseminated among the stakeholders involved during Step 1 of my research, with the intention of getting their feedback on the final product and validate or improve the result. This was done to facilitate an iterative process of participation that feeds back on itself, framed under the guidelines of adaptive collaborative management.

[19] Metrics at the landscape and class level were calculated considering the corresponding sub-basins as the total analysis area.

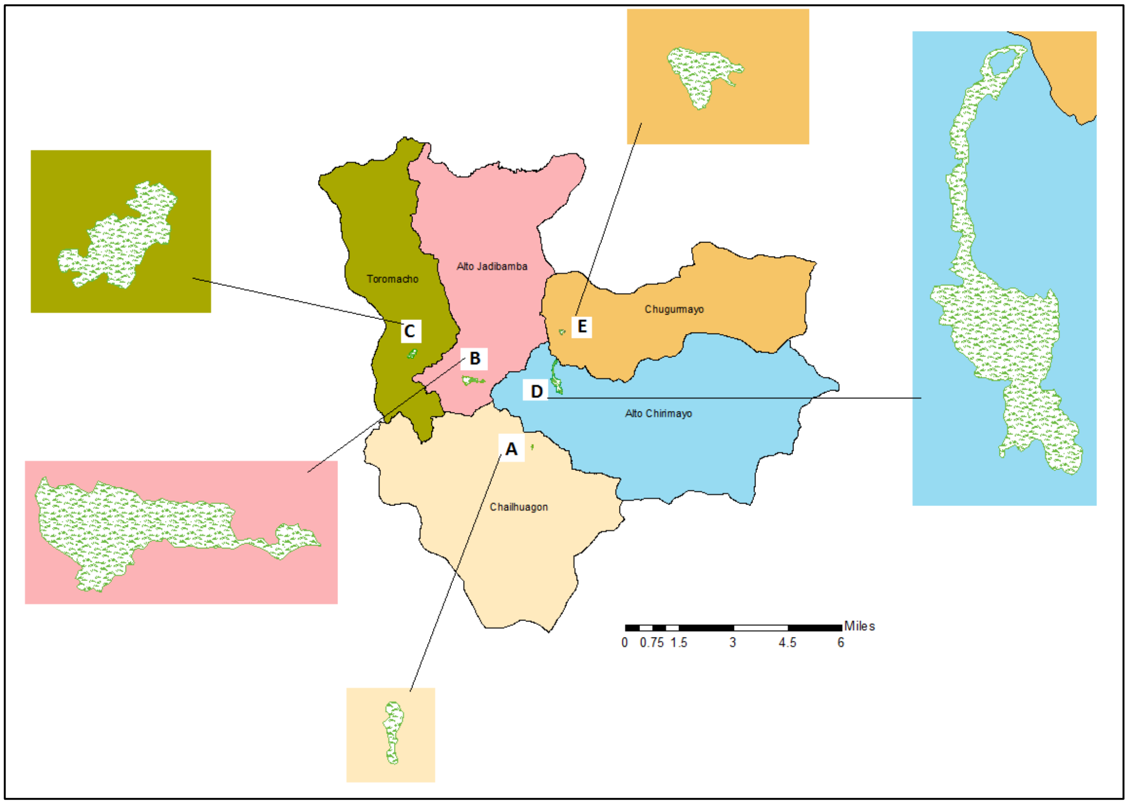

Figure 7 Potential offset sites for the biodiversity offset case study

Through this approach, stakeholders ideally engage in a process of effective social interaction in which they negotiate a common vision, undertaking shared learning in developing and implementing plans for its achievement; they then jointly reflect on the outcomes of such plans, continually seeking and negotiating together corresponding innovations and improvements (Center for International Forestry Research, 2007).

The final objective of this research is to provide future and current stakeholders implementing, monitoring, and/or regulating offsetting schemes a structured decision making tool to work from for the implementation, evaluation, and regulation of such projects. Considering the achievement of no net loss of biodiversity as the ultimate common goal, this tool can be used as: a planning guideline for developing or refining biodiversity offset programs; a common frame of reference for collaboration and sharing best practices and lessons learned; a tool to support the development of a monitoring program to evaluate the effectiveness of the strategy implemented; among others. The tool was developed under the 'human-centered' or 'design thinking' approach, which is human-centered, options focused, possibility driven, and iterative, embracing empathy for the user (i.e., the stakeholders) (Brown, 2008).

4. CHAPTER 4: RESULTS AND DISCUSSION

This chapter presents and analyzes the nine products obtained throughout the five steps of my research, which are outlined in Figure 1 (Chapter 3) and Table 12.

Table 12 Steps and corresponding products of my research

Step	Products
Step 1	**P1:** Set of relevant and validated criteria that metrics for assessing the balance between offset gains and project impacts should comply with to qualify as effective and practical
Step 2	**P2a:** Matrix comparing core principles of available biodiversity offset metrics.
	P2b: Matrix characterizing available biodiversity offset metrics according to indicator desirable properties (Munn, 1988; Noss, 1990), attributes of suitable forms of metrics (BBOP, 2012) and stakeholders' criteria (identified in Subsection 4.1).
	P2c: Decision tree for determining the 'best fit' metric.
Step 3	**P3a:** Description of the proposed OPLM and its development process.
	P3b: Description of the OPLM structure as a decision making tool for the implementation and evaluation of biodiversity offsets according to specific model components and offset principles.
Step 4	**P4a:** Comparison of biodiversity offset requirements and assessment of suitability of potential offset areas in terms of the identified requirements using different metrics for the BOCS analyzed.
	P4b: Assessment of offset performance across space using the developed OPLM for the selected BOCS.
Step 5	**P5:** Decision making tool for the implementation of successful biodiversity offset strategies in Latin America, their evaluation and regulation.

Key:
P = Research products; OPLM = Offset Performance Logic Model; BOCS = Biodiversity offset case study

4.1. Step 1: Definition of what is an 'appropriate' metric for biodiversity offsets in Latin America according to stakeholders' criteria

As described in Subsection 3.1, a series of unstructured conversations and discussions were conducted with stakeholders involved in the design, implementation, and evaluation of biodiversity offsets across Latin America and worldwide. They were asked about the relevant criteria/attributes that the available alternative metrics should comply with to qualify as effective and practical when assessing the balance between offset gains and project impacts.

According to their academic and professional backgrounds and experiences in the field, stakeholders highlighted a wide variety of different criteria and attributes that metrics should comply with. However, in general, consensus was found in the six aspects described below. These constitute the set of relevant criteria that metrics for assessing biodiversity offset equivalencies should comply with in order to qualify as effective and practical (Product P1, see Figure 1 and Table 12).

- **The conservation target should be focused at an ecosystem or habitat level within a landscape:** According to Noss (1990), biodiversity can be classified into four different levels of organization: landscape, ecosystem, species, and genetic. Stakeholders agreed that no net loss should be achieved at an ecosystem or habitat level, and that these should be managed under a landscape context approach. Nevertheless, several stakeholders emphasized the fact that the specific conservation target should ultimately depend on the project's objectives and context.

- **The metric's inputs/indicators should require objective (quantitative) values only:** Several current indicators are fully or partially based on qualitative analysis of the conservation targets, obtaining values of biodiversity that are dependent of the evaluator's subjective criteria (e.g., Module Assessment method). Subjective judgment can become a problem, especially when different evaluators participate in the process. In this sense, several stakeholders mentioned the need to develop indicators that are based only in quantitative analysis, allowing the comparison of data obtained across different areas and monitored by different evaluators.

- **Metrics should consider benchmark areas:** A benchmark area presents the average characteristics of a mature and apparently undisturbed patch of the same vegetation type as the one being assessed. Its purpose is to act as a reference of the optimum state of the habitat type being assessed, measuring losses and gains against it. Stakeholders indicated its importance in understanding the numerical values obtained in the different indicators assessed, as well as in determining the significance of any changes in such values over time and space.

- **Metrics should be practical and cost effective:** Several metrics used to assess the balance between losses and offset gains are intensive and complex, requiring trained operators to ensure consistent results (e.g., Habitat Hectares; Parkes, Newell, & Cheal, 2003); in several others, the level of resources required is generally medium to high, depending on the availability of appropriate information (e.g., Conservation Significance Index; Virah-Sawmy, Ebeling, & Taplin, 2014). Given this situation, stakeholders highlighted the need of developing metrics that are both, scientifically rigorous and efficient in terms of cost and time. The idea is to encourage project developers to use and implement such metrics, for which their practicality represents a critical factor.

- **The indicators considered within each metric should depend on the biodiversity target being assessed:** Indicators used to assess project impacts/offset gains in a forest should not be the same as those used to calculate such measures in a desert. Although the accounting method could be equivalent, the specific metrics or indicators contained within should be context dependent. For example, in the Habitat Hectares approach (Parkes, Newell, & Cheal, 2003), assessments of treeless vegetation types require the removal of inappropriate indicators, and standardizing the habitat score for the remaining ones, reducing the level of discrimination within these vegetation types.

- **Metrics should be complemented by considering 'special values':** Capable of modifying the metric's final results, these 'special values' should include: presence of sensitive species, high conservation value of the habitat/ecosystem type being assessed, relevant ecosystem services, significant concentrations of migratory species, cultural values, magnitude of the generated impact, among others. These 'special values' are usually integrated through the use of multipliers, used to increase the amount of biodiversity gains required. In this sense, independently of the metric used to calculate the balance between project impacts and offset gains, several stakeholders highlighted the need of integrating within the corresponding method multipliers that consider the presence of special features in the landscape being assessed.

4.2. Step 2: Review and characterization of existing metrics and their implications

The results of Step 2 of my research method were designed to answer each of the three proposed review questions indicated in Subsection 3.2. Each answer involved the development of a specific product, as detailed in Table 13 (also see Figure 1 and Table 12 for further details).

Table 13 Review questions and the corresponding products obtained as part of Step 2

Review Question	Product
(1) What are the different available metrics for measuring biodiversity values in the context of offsetting strategies and how are they characterized?	**P2a:** Matrix comparing core principles of available biodiversity offset metrics.
(2) What are the best currently existing metrics for measuring biodiversity values in Latin America in the context of offsetting strategies (according to standardized frameworks and stakeholder's criteria)?	**P2b:** Matrix characterizing available biodiversity offset metrics according to indicator desirable properties (Munn, 1988; Noss, 1990), attributes of suitable forms of metrics (BBOP, 2012) and stakeholders' criteria (Subsection 4.1).
(3) For what biodiversity offset project scenario is each metric more suitable?	**P2c**: Decision tree for determining the 'best fit' metric.

Key:
P = Research products

4.2.1. Product P2a - Matrix comparing core principles of available biodiversity offset metrics

This product is presented in Appendix A, and summarized in Table 14. It was developed to answer the first review question: What are the different available metrics for measuring biodiversity values in the context of offsetting strategies and how are they characterized? As presented in Table A-1, there are 13 general types of biodiversity offset metrics for terrestrial ecosystems, including wetlands, from which other more specific metrics derive. These metrics respond to different creation objectives, which dictate the biodiversity target being assessed, the formula and indicators used, and the methodological process implied. Other characteristics that do not necessarily respond to the metrics' creation objectives, such as a consideration of the landscape context and/or benchmark area, also differentiate one metric from another, making some more robust than others.

In general, most of the assessed metrics target ecological communities or ecosystems and consist of pre-defined indicators (more than one). All of these indicators target at least the composition attribute of biodiversity (defined by Noss, 1990), while a few also address structure; only four of the considered metrics focus at the three attributes of biodiversity, including function. Regarding the use of benchmark areas, only three of the assessed metrics considered them when valuating losses and gains.

Finally, from the set of 13 metrics assessed, only three included some sort of a landscape perspective. According to Quétier and Lavorel (2011), if losses and gains are assessed in terms of a site's 'quality x area', then that quality should take into account the site's location in the ecological landscape, in relation to other patches of the same or similar habitat types, in relation to fragmentation and connectivity issues, and in relation to the landscape's functional processes.

Table 14 Comparison of core principles of selected metrics for assessing biodiversity values*

Metric/ framework it is part of	Offsetting target			Use of indicators					B	LC
	Specific target	Level of organization		Type	Single or several?	Biodiversity attributes				
		Noss, 1990	TNC, 2003			C	S	F		
Habitat - hectares	Native vegetation communities	Community - ecosystem	Ecological communities	Pre-defined	Several	X	X	X	Yes	Yes
Units of Global Distribution	High priority species	Population - species	Species	Pre-defined	Single	X	-	-	No	No
Uniform Mitigation Assessment Method	Ecosystem services/ wetland functions	Community - ecosystem	Ecological communities	Pre-defined	Several	X	X	X	No	Yes
Biodiversity Significance Index	Native vegetation communities	Community - ecosystem	Ecological communities	Pre-defined	Several	X	X	X	Yes	Yes
Conservation Significance Index	High priority species	Population - species	Species	Pre-defined	Several	X	-	-	No	No
US Wetland Banking/ compensatory mitigation	Wetland habitat	Community - ecosystem	Ecological community	Case dependent	Single	X	-	-	No	No
US Conservation Banking	Species	Population - species	Species	Case dependent	Usually single	X	-	-	No	No
Adaptation of Habitat Hectares (DEFRA)	Habitat	Community - ecosystem	Ecological community	Pre-defined	Several	X	X	X	No	No
Module Assessment method	Habitat	Community - ecosystem	Ecological community	Pre-defined	Several	X	X	-	No	No
Biotope Valuation	Habitat	Community - ecosystem	Ecological community	Pre-defined	Several	X	X	-	No	No
Habitat Units	Individual species	Population - species	Species	Case dependent	Depends				Yes	No
Significant Environmental Benefit	Native vegetation	Community - ecosystem	Ecological communities	Pre-defined	Several	X	X	-	No	No
Offset ratios	Ecosystem	Community - ecosystem	Ecological communities	Pre-defined	Single	X	-	-	No	No

(*) Summary of the results presented in Appendix A
Key:
C = Composition; S = Structure; F = Function; B = Benchmark; LC = Landscape context

4.2.2. Product P2b - Matrix characterizing available biodiversity offset metrics according to established frameworks and stakeholders' criteria

This product is presented in Appendix B, and was developed to answer the second review question: What are the best currently existing metrics for measuring biodiversity values in Latin America in the context of offsetting strategies, according to standardized frameworks and stakeholders' criteria? The frameworks considered were indicator desirable properties (Munn, 1988; Noss, 1990) and attributes of suitable forms of metrics (BBOP, 2012). Table 15 presents a summary of the results determined and presented in Appendix B.

Table 15 Total final scores for each biodiversity offset metric considered

Metric	Total final score
Biodiversity Significance Index	2.10
Habitat Hectares	1.90
Conservation Significance Index	1.70
Biotope Valuation	1.40
Significant Environmental Benefit	1.30
DEFRA metric	1.13
Offset ratios	1.10
Uniform Mitigation Assessment Method	1.10
US Wetland Banking	0.93
Module Assessment method	0.90
Habitat units	0.87
Units of Global Distribution	0.57
US Conservation Banking	0.50

According to these results, in relation to the indicator desirable properties outlined by Munn (1988) and Noss (1990), the attributes of suitable forms of metrics identified by the BBOP (BBOP, 2012) and stakeholders' criteria, the Biodiversity Significance Index (BSI) would be the most suitable metric for measuring impact losses and offset gains in Latin America, followed by the Habitat Hectares (HH) approach (within the analyzed set of current metrics). Both types of metrics are based on an 'area x quality' formula; however, in the first case, the 'quality' of the environment is determined by its condition, biodiversity significance, conservation significance, land use change, and landscape context, while in the second case only by its condition and landscape context. According to the stakeholders' criteria, the integration of 'special values' (e.g., biodiversity and conservation significance) is of utmost importance when assessing the balance between offset gains and project impacts in Latin America.

The BSI is a metric based on the HH approach, modified according to current and proposed land uses. It can be used at different spatial scales to evaluate vegetation and landscape condition. Besides being characterized by three of the six stakeholders' criteria (Appendix B), the relatively high score obtained can be explained by the following: (1) the metric's capability of providing a continuous assessment over a wide range of stresses; (2) its relevancy to ecologically significant phenomena; (3) ability to capture type, amount, and condition of the conservation target; and (4) the inclusion of context dependent information about the importance of the biodiversity component(s) assessed. However, it is important to mention that the land use types considered by this metric are only applicable to the New South Wales (NSW) Environmental Services Scheme. Likewise, the Conservation Significance categories included are based on those used within the

NSW vegetation classification database, reason why it obtained a low score regarding geographic applicability.

The metrics that had the lowest final scores (see Table 15; Units of Global Distribution and US Conservation Banking) exhibited only one of the six stakeholders' criteria (Appendix B). Both metrics consider species as the conservation target, lack objectivity (i.e., results are qualitative and depend on the evaluator), have indicators that are not target type dependent, and do not provide the possibility of including 'special values' in the accounting process. Although these metrics presented the lowest final scores, they might still be useful in specific situations, and under specific project contexts.

As stated in Chapter 1, current metrics for accounting equivalences are not suitable for all situations, and therefore should not be directly extrapolated into any offsetting scheme without previous evaluation of their implications. The mechanisms used should depend on the characteristics of the biodiversity interests and the specific scheme's final objectives (DEFRA, 2011). In this sense, according to Bull, Suttle, Gordon, Singh, and Milner-Gulland (2013), choosing the most appropriate measurement framework for a biodiversity offsetting strategy from a wide set involves much more than simply selecting characteristic or representative components of the ecosystem in question. It also requires a clear decision regarding the fundamental objective of the offset policy, which in this case, according to the mitigation hierarchy, involves achieving no net loss, or a net gain, of biodiversity. This situation led to the third review question (see Subsection 4.2.3).

Finally, it should be taken into account that, although the maximum possible final score (FS-3) is six, all of the obtained results are below half of such maximum possible value (see Table 15). Appendix B shows that none of the metrics assessed enable the calculation of residual losses and gains of the use and cultural values associated with biodiversity (one of BBOP's attributes of suitable forms of metrics); few of them have the ability to differentiate between natural and anthropogenic-induced cycles or trends (indicator desirable properties according to Munn [1988] and Noss [1990]); and only a a few include indicators that are specific to the type of environment/target being assessed, take into account objective numerical values, and consider benchmark areas (stakeholders' criteria).

These results support the need for exploring, creating, and structuring a more comprehensive tool for stakeholders to use when evaluating the success of biodiversity offsetting strategies in Latin America. Furthermore, this tool needs to cover the previously identified gaps, overcoming the detected limitations, and strengthening the recognized advantages of currently existing accounting methods. This new framework could be built from the already existing metrics and accounting approaches, expanding on their advantages and proposing further analyses where needed.

4.2.3. Product P2c - Decision tree for choosing the 'best fit' metric option

This product (Appendix C) was developed to answer the third and last review question: Under what biodiversity offset project scenario is each metric more suitable? This decision tree aims at helping stakeholders select the most adequate metric for their specific biodiversity offset project. The decision nodes, shown as squares, represent a point where a choice must be made. The branches extending from each decision node correspond to decision branches, each representing one of the possible alternatives or courses of action available at that point (each set of alternatives is mutually exclusive and collectively exhaustive). The event nodes, shown as circles, represent a point where uncertainty is resolved (a point where the decision maker learns about the occurrence of an event). The branches extending from each decision node correspond to event branches, each representing one of the possible events that may occur at that point.

In general, decision nodes and branches represent the controllable factors in a decision problem; event nodes and branches represent uncontrollable factors. The tree was constructed considering as decision nodes and events the principal differentiating characteristics between the different metrics assessed, giving emphasis to those characteristics considered important by the stakeholders involved. Finally, the terminal nodes (end points of the decision tree, highlighted as orange circles), represent the final result of a combination of decisions and events: the most appropriate (or 'best fit') biodiversity offset metric considering the selected conditions.

4.2.4. Integration of Products P2a – P2c

When selecting appropriate metrics for calculating the balance between impact losses and offset gains, Products P2a, P2b, and P2c (see Figure 1 and Table 12) could and should be used in conjunction. Together, these represent a useful tool to guide stakeholders through the corresponding decision making process.

The matrix comparing core principles of available biodiversity offset metrics (Product P2a, see Figure 1) acts as a menu of the available metrics and their main characteristics. A stakeholder could use it to learn about the different types of existing metrics and how they differ. The matrix characterizing available biodiversity offset metrics according to established frameworks and stakeholders' criteria (Product P2b, see Figure 1) provides information about how these comply with what is expected in terms of the best practices for measuring ecological equivalences. Finally, the decision tree (Product P2c, see Figure 1) makes a recommendation of a specific metric according to a specific project context. Such recommendation should be re-visited and validated using the first two products.

4.3. Step 3: Development of a logic model for assessing offset performance over time and across space

Step 3 involved the development of two products: P3a, description of the Offset Performance Logic Model (OPLM) and its development process, and P3b, description of the OPLM structure as a decision making tool for the implementation and evaluation of biodiversity offsets according to specific model components and principles. These products are outlined in Figure 1, Table 12 and presented below.

4.3.1. Product P3a – Description of the Offset Performance Logic Model and its development process

The OPLM was developed following the five steps of the modelling process proposed by Sterman (2000), as described in Subsection 3.3 (see Table 9).[20] The results of each of the first three steps are detailed below. The last two stages of the process are developed as part of Steps 4 (Subsection 4.4) and 5 (Subsection 4.5) of my research, respectively.

4.3.1.1. Problem articulation

For Application 1 (selection of the most appropriate offset site from a set of potential offset areas [i.e., analysis across space]; see Subsection 3.3), once the most appropriate metric is selected, the set of potential offset areas that provide the calculated offset requirements is used as an input for the OPLM. The model answers the question: What is the best offset area alternative? As a result or output, it then determines which area performs the best in terms of its ecological equivalence to the impact area within a specific landscape context (Figure 8). In this case, the OPLM contributes towards solving the problem of the lack of systematic tool for selecting an offset area that provides the corresponding offset requirements by considering its location within the landscape.

[20] It should be emphasized that the OPLM represents an additional further step, complimentary to the use of existing metrics for valuing equivalences; it does not act as a stand-alone tool, nor replaces the use of biodiversity offset metrics.

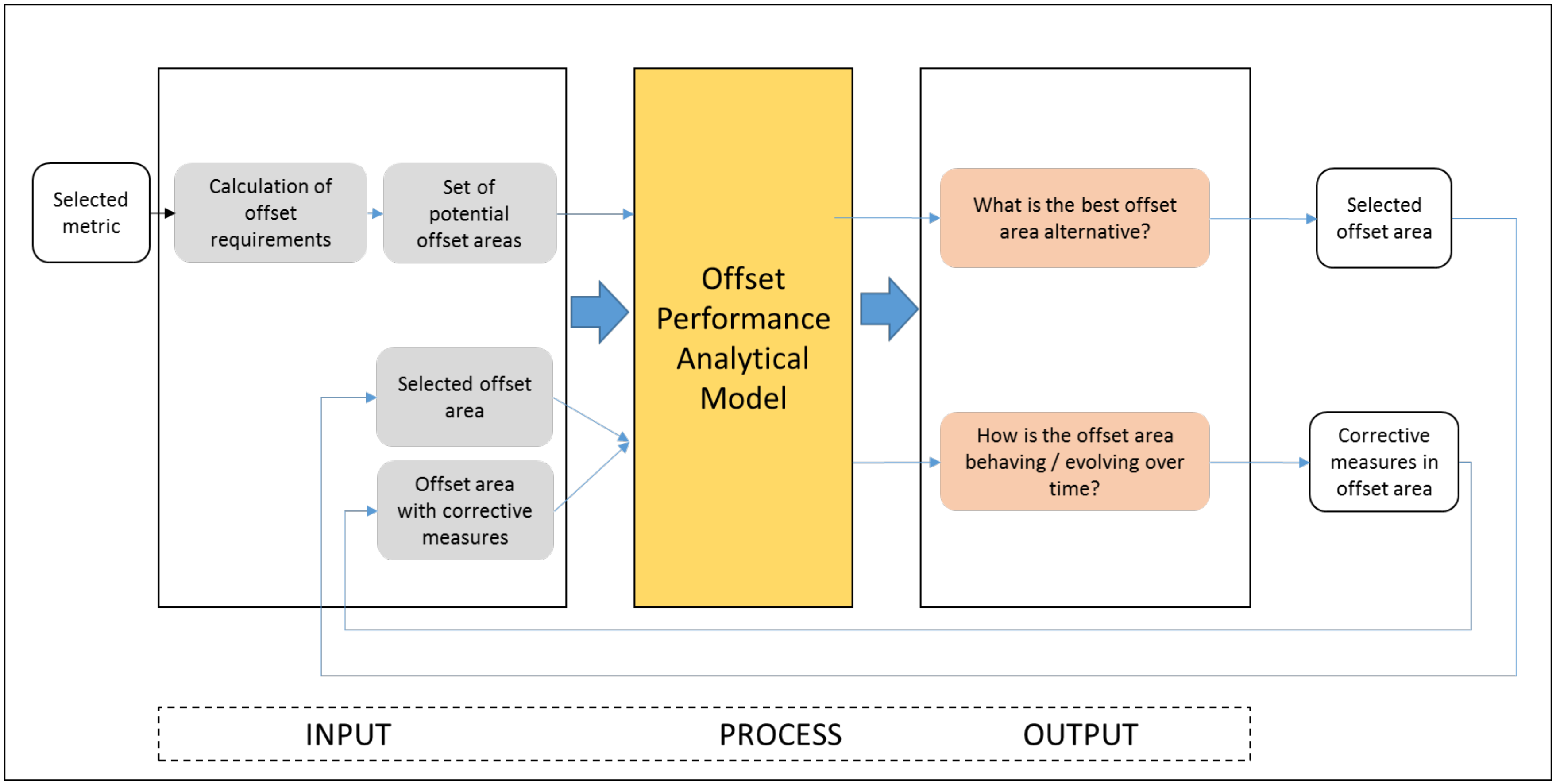

Figure 8 Inputs, process, and outputs of the Offset Performance Logic Model

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Considering the Application 2 (monitoring of the development of a specific established offset area [i.e., analysis over time]; see Subsection 3.3), once an offset area has been selected and established, the selected area is used as a model input. The OPLM answers the question: How is the offset area behaving/evolving over time? As a result or output, it then determines the necessity of implementing corrective measures as part of an integrative adaptive management process (see Figure 8). It also provides information about which landscape characteristic should be tackled through these corrective measures. In this sense, it comprises a useful planning tool for determining what actions may best influence the situation at a specific site and what factors should be monitored to determine if these are changing (and how) with the project implementation, contributing towards solving the problem of the lack of a systematic tool for assessing if an offset area is compensating what has been lost over time, in relation to the location of both areas in the landscape.

4.3.1.2. Dynamic Hypothesis

In case of Application 1, the theory I am addressing behind the problematic behavior consists in that existing metrics do not consider (or appropriately consider) the landscape context when determining offset requirements and selecting the most appropriate offset site. Although these metrics usually allow the accounting of equivalences in terms of the areas' quality (based on specific biodiversity indicators), the landscape contexts in which these sites are embedded (which might present different structures and support different processes), usually fail to be represented when developing such quality calculations. This is of special importance when trying to achieve a no net loss of biodiversity, considering that the long-term viability of biodiversity at offset sites critically depends on the structure (e.g., connectivity) and function (e.g., colonization and dispersal processes) of the landscape being represented (Bennett, 2003).

In the case of Application 2, the theory I am addressing points out to the fact that existing accounting methods do not provide the necessary tools or frameworks for monitoring the performance or evolution of an offset area over time in terms of the landscape's composition, structure, and function. Landscapes are dynamic systems susceptible to disturbances, and their changing performance over time might affect the viability of biodiversity at the offset site, resulting in a net loss of biodiversity.

Regarding the mapping component of this stage of the modeling process, Figure 8, presents a flow diagram of the Offset Performance Logic Model processes and activities.

4.3.1.3. Formulation of a simulation model

The process followed for developing the model (which included target identification, characterization, and scoring) is detailed in Subsection 3.3. Below is a description of the results obtained for each stage.

Identification of offsetting targets

According to TNC's (2003) 5-S Framework, conservation targets (in this case offsetting targets) may include the following: ecological systems, ecological communities, and species. The proposed model focuses on ecological systems, which refers to conservation targets at the highest level of biodiversity organization. TNC (2003) defines this type of target as ecological communities "aggregated into dynamic assemblages or complexes that (1) occur together on the landscape; (2) are linked by ecological processes, underlying environmental features (…), or environmental gradients (…); and (3) form a robust, cohesive, and distinguishable unit on the ground" (p. IV-1).[21] Accordingly, ecological systems occur at three geographic scales: local (i.e., patch), intermediate (i.e., large group of patches), and coarse (i.e., matrix of habitats). These three scales are incorporated in the OPLM.

Characterization of offsetting targets

- **Indicator selection:**

  Appendix D presents a detailed description of the indicators proposed to adequately assess the characteristics of the offsetting targets per objective (criterion), including their importance and applicability. Table 16 presents a summary of this information.

[21] Although the proposed model focuses on ecological systems, 'special values' such as threatened and migratory species are also considered and incorporated to the accounting process through the use of multipliers (see Subsection 4.3.1.3)

Table 16 Set of landscape metrics proposed for characterizing offsetting targets*

Objective	Criteria for characterizing offset target (TNC, 2003)	Attribute of biodiversity (Noss, 1990)	Performance criteria	Indicator	Metric level	Alternative indicators
Achieve offset gains that are equivalent to project impacts in terms of size	Size	-	Equivalent/larger core area of targeted offset patch	CAI - Core Area Index	P	Core Area
Achieve offset gains that are equivalent to project impacts in terms of condition	Condition	Structure	Equivalent/lower dispersion of patches at offset area	CLUMPY - Clumpiness index	C	Aggregation Index; Patch Cohesion Index
			Equivalent/lower interspersion of patches at offset area	IJI - interspersion / juxtaposition index.	C	-
			Equivalent/lower subdivision of patches at offset area	SPLIT - splitting index	C	Landscape Division Index; Effective Mesh Size
			Equivalent/lower isolation of patches at offset area	CONNECT - Connectance Index	C	Euclidean Nearest Neighbor Distance; Proximity Index; Similarity Index
		Function (biotic interactions)	Equivalent/lower proportional abundance of edge influenced habitat	ED - edge density	C	Total Edge
		Composition	Equivalent/higher landscape diversity at offset area	SHDI - Shannon's diversity index	L	Simpson's diversity Index; Modified Simpson's diversity Index
Achieve offset gains that are equivalent to project impacts in terms of landscape context	Landscape context	Function (processes and regimes)	Equivalent/higher complexity at offset area	PAFRAC - Perimeter-area fractal dimension	L	Shape Index ; Fractal dimension index
		Structure (connectivity)	Equivalent/higher landscape connectivity at offset area	GYRATE_AM - Correlation length	L	Patch Cohesion Index; Contagion Index

(*) Summary of the information presented in Appendix D
Key:
Metric level: L = Landscape; P = Patch; C = Class

In the case of the function indicators, it is important to mention that, according to Noss (1990), these should include variables such as: nutrient cycling rates, energy flow rates, disturbance processes, colonization rates, biomass and resource productivity, among others. However, given the complexity of such indicators in terms of the time and data requirements involved, Edge Density (ED) and Perimeter-Area Fractal Dimension (PAFRAC) were chosen as proxy measures for function, assuming that these have a close relationship with the biotic interactions of the habitat addressed, in the first case, and with the environmental regimes and processes of the landscape, in the second.

ED was chosen as a proxy measure for characterizing biotic interactions considering that edges are often responsible for increased predation and the invasion of exotic plant species and, in many cases, act as barriers for animal movement (McGarigal, n.d.). Regarding the latter, the boundary between patches can function as a differentially-permeable membrane that facilitates some ecological flows while impeding others, or as a semi-permeable membrane that partially impairs flows (McGarigal, n.d.).

PAFRAC was selected as a surrogate measure for characterizing environmental regimes and processes, taking into account that size-shape relationships can influence a number of important ecological and environmental phenomena, such as animal dispersal, surface water runoff, speciation, and extinction (Burguess & Sharpe, 1981). In addition, the fractal dimension of patch shapes suggests common ecological processes or anthropogenic influence affecting patches, and differences between landscapes can suggest differences in the underlying pattern-generating process (e.g., Krummel, Gardner, Sugihara, O'Neill, & Coleman, 1987).

Finally, it is important to mention that, although the proposed indicators are thought to be applicable to general situations, alternative variables have been proposed in each case (Appendix D); which indicator to use should depend on each project's specific context, selecting indicators that are ecologically meaningful in each specific situation. This represents a key issue in the proposed model, as determining which indicators of landscape performance to use is vital to producing an assessment that will tell stakeholders whether or not their landscape is moving in the right direction with respect to their goals (Buck, Milder, Gavin, & Mukherjee, 2006). Ecoagriculture Partners' Landscape Measures Resource Center[22] provides good guidelines for the selection of appropriate indicators for each criterion presented.

- **Indicator calculation:**

  When using the OPLM, the selected indicators need to be calculated in both the impact and the offset area, in order to compare the results obtained and assess how well the offset area is performing in relation to the impact site

[22] See: http://landscapemeasures.info/

across time (monitoring purposes) and/or space (selection between different potential offset areas within a specific landscape). Also, for reference purposes, the indicators need to be calculated in a benchmark area, which correspond to the most un-impacted or pristine area of the same habitat type as the one being assessed. Below a definition of the three area types being considered: impact, offset, and benchmark.

- **Impact area:** area that is going to be affected by the project, either directly, by the removal of topsoil and the implementation of infrastructure (project footprint) or indirectly, by impacts linked to infrastructure development, before these occur (i.e., without project scenario). It corresponds to the area that needs to be offset.
- **Offset area**: area managed to offset the impacts of the impact area. It could be analyzed before the offset measures are implemented (i.e., conservation and/or management strategies), establishing a baseline, or/and after the measures are implemented, for monitoring purposes.
- **Benchmark area:** represents the average characteristics of a mature and undisturbed state of the vegetation type/ecosystem being assessed.

The extent and grain of the three mentioned areas, impact, offset, and benchmark needs to be equivalent.

Scoring of offsetting target

To understand the performance of the selected condition and landscape context indicators, and the meaning of the values obtained in the impact and offset area (in terms of the target's condition), a ranking system is needed. This system was build using the minimum and maximum possible values of the corresponding selected indicators, which define the two ends of the spectrum (i.e., minimum and maximum boundaries) of the ranking system for the evaluation of the results obtained. These boundaries would help to determine how significant the differences are between the results obtained per indicator in the impact and offset areas. For example, the difference between a result of '3' in the impact area, and '5' in the offset area for a specific indicator could be considered significant in case its scale goes from '2' (minimum boundary) to '6' (maximum boundary), but insignificant within a scale of '0' (minimum boundary) to '100' (maximum boundary).

Moving forward, in order to integrate the broad set of generated results (eight indicators for three different areas) into a visual device that can be practically used by offsetting planners, I propose incorporating the different condition and landscape context indicators calculated into an AMOEBA diagram.[23] This is a specific type of radar diagram consisting of concentric circles of increasing radios that represent a value in a determined scale and present information on various axes simultaneously (Sayer et al., 2006; Ten Brink, Hospers, & Colijn, 1991). It is

[23] A Dutch acronym for General Method for Ecosystem Description and Assessment. This approach was developed in the Netherlands in 1989 to serve as an evaluating framework for the ecological quality of water systems (Ten Brink, Hospers, & Colijn, 1991).

used to visually assess a system's condition relative to an optimal one, which in this case corresponds to the offset area relative to the impact area). The construction of the AMOEBA diagram (using Microsoft Excel) follows the following characteristics.

- The numbers for feeding the diagram (results obtained for each indicator and area) are normalized and turned into standardized values based on a common scale, where '1' corresponds to the 'best' possible scenario and '0' to the 'worst'. The results obtained in the offset, benchmark, and impact area are considered for the normalization purposes, as well as the maximum and minimum possible values per indicator.
- Each indicator is shown graphically as the diagram's axis.
- Each diagram contains four different series of data:
    - Minimum and maximum boundaries: corresponding to minimum and maximum possible values of each indicator – inner and outer limits of acceptable change.
    - Offset values: corresponding to the current estate of the offset area.
    - Impact values: corresponding to the goal/reference value.
    - Benchmark values: corresponding to the best possible value in the specific landscape being assessed and at a specific time.
- The values of each series are marked and linked through lines, creating the shape of an amoeba.

Figures 9 and 10 present hypothetical examples of AMOEBA diagrams for the condition and landscape context indicators, developed following the considerations described above. Both diagrams present the results for the four different series of data (i.e., minimum and maximum boundaries, offset, impact, and benchmark values) for each of the eight indicators considered. The closer the results of the offset area to those of the impact area (as in Figure 9, in comparison to Figure 10), the more ecologically equivalent both areas are, in terms of the indicators being assessed.

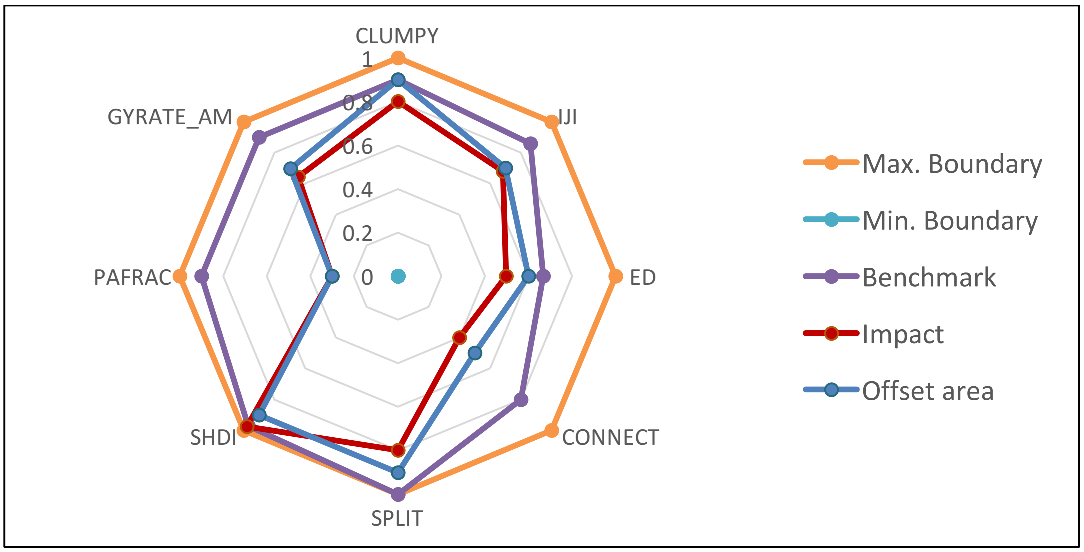

Figure 9 Example of an AMOEBA diagram integrating the condition and landscape context indicators where the offset area is suitable for offsetting the impacts

Key:
Indicators: SHDI = Shannon's diversity index; SPLIT = Splitting index; CONNECT = Connectance index; ED = Edge density; IJI = Interspersion index; CLUMPY = Clumpiness index.

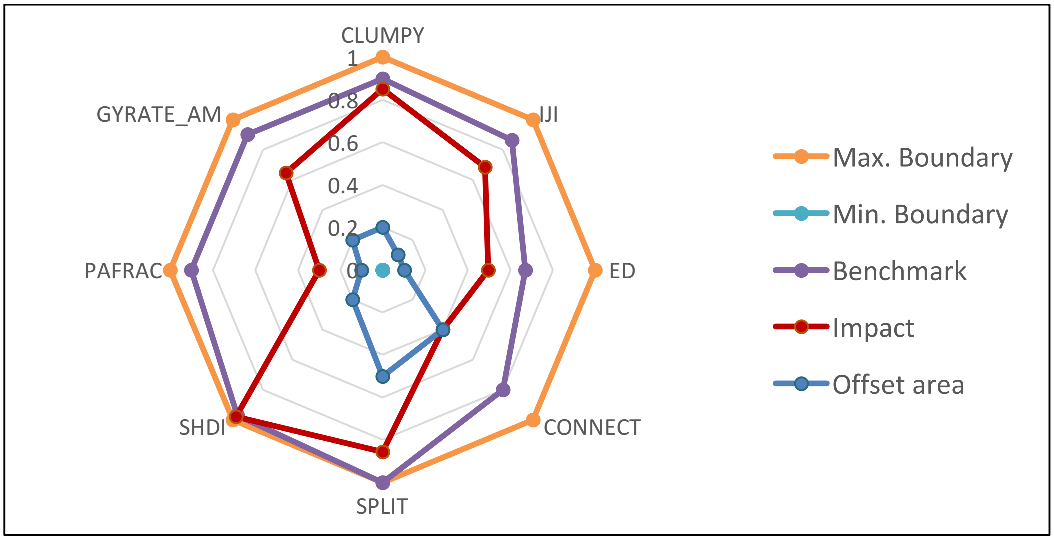

Figure 10 Example of an AMOEBA diagram integrating the condition and landscape context indicators where the offset area is not suitable for offsetting the impacts

Key:
Indicators: SHDI = Shannon's diversity index; SPLIT = Splitting index; CONNECT = Connectance index; ED = Edge density; IJI = Interspersion index; CLUMPY = Clumpiness index.

Offset results higher than the impact results (i.e., closer to the maximum boundary, as in Figure 9) suggest that the offset area is over-performing in comparison to the impact area for such indicators; while offset results lower than the impact results (i.e., closer to the minimum boundary, as in Figure 10) suggest that the offset area is under-performing in comparison to the impact area for those specific landscape metrics, The benchmark area results can be used as a reference of the maximum (i.e., 'best') values than can be expected for both the offset and impact areas.

The advantages associated with integrating the results in this type of model include the following.

- The AMOEBA diagram pools indicators together in a visual manner, giving an overall visual effect of integration without aggregating the obtained results. Unlike some other approaches that create and use a single value or indicator, these diagrams keep the richness intact and let the reader interpret their meaning (Bell & Morse, 2008; Buck, Milder, Gavin, & Mukherjee, 2006;).
- The results per indicator will show how healthy the target is in relation to a benchmark area, for both the impact and offset areas independently.
- By analyzing the selected indicators independently, it is possible to identify the key landscape aspects that need to be strengthened/enhanced to improve the overall outcome, creating the opportunity to integrate the proposed tool with the process of adaptive management.
- The AMOEBA diagram allows determining where flaws occur, distinguishing the issue areas, and drawing some conclusions about corrective actions. Further investigation and feasibility analysis can be performed to ensure that sufficiently informed decisions are made.

Calculation of Offset Performance Value

Through the Offset Performance Logic Model (OPLM) an Offset Performance Value (OPV; Equation 2) is obtained. This value is calculated in terms of weighted area, offering a quantity-quality-context measure: offset's size value multiplied by the arithmetic sum of the condition and landscape context values. The size value is determined by the selected indicator within this criterion (core area index [CAI]).

The condition and landscape context values are determined by the arithmetic sum of the percentage change between the indicator values at the offset area and impact area, after normalizing the results, which is known as the ecological Dow Jones index (EDJI; Kuik & Verbruggen, 1991).

Equation 2 Offset Performance Value (OPV)

$$OPV = CAI \times \left\{ \underbrace{\left[\frac{(\sum_{i=1}^{6} C.Oi) - (\sum_{i=1}^{6} C.Ii)}{(\sum_{i=1}^{6} C.Ii)} \times 100\right]}_{\text{EDJI\_condition criterion}} + \underbrace{\left[\frac{(\sum_{i=1}^{2} L.Oi) - (\sum_{i=1}^{2} L.Ii)}{(\sum_{i=1}^{2} L.Ii)} \times 100\right]}_{\text{EDJI\_landscape criterion}} \right\}$$

Where:
EDJI = Ecological Dow Jones Index
i = indicators selected for the condition and landscape context criteria
CAI = Core Area Index
C.O = normalized values of indicators selected for the condition criterion, calculated in the offset area.
C.I = normalized values of indicators selected for the condition criterion, calculated in the impact area.
L.I = normalized values of indicators selected for the landscape context criterion, calculated in the impact area
L.O = normalized values of indicators selected for the landscape context criterion, calculated in the offset area

EDJI values can be negative, positive, or zero. Negative values are obtained when the arithmetic sum of the results of the indicators in the offset area is smaller than the arithmetic sum of the indicator values on the impact area (either for the condition or landscape context criterion). According to the model, negative values suggest that the offset area is under-performing in relation to the impact area in one or both criteria, and thus:

- The area does not represent an adequate alternative for offsetting the corresponding impacts (in the case of analyses across space); or
- Corrective management measures should be implemented in the area to address the situation, through the process of adaptive management (in the case of analyses over time), and monitoring activities should continue over time (Figure 11).

On the other hand, positive EDJI values are obtained when the arithmetic sum of the results of the indicators in the offset area is greater than the arithmetic sum of the indicator values on the impact area (either for the condition or landscape context criterion). According to the model, positive values suggest that the offset area is over-performing in relation to the impact area in one or both criteria, and thus:

- The area represents an adequate alternative for offsetting the corresponding impacts (in the case of analyses across space); or
- A net gain of biodiversity is evidenced and thus the offsetting strategy can be considered sucessful (in the case of analyses over time). There is no need to implement corrective management measures at this point (see Figure 11).

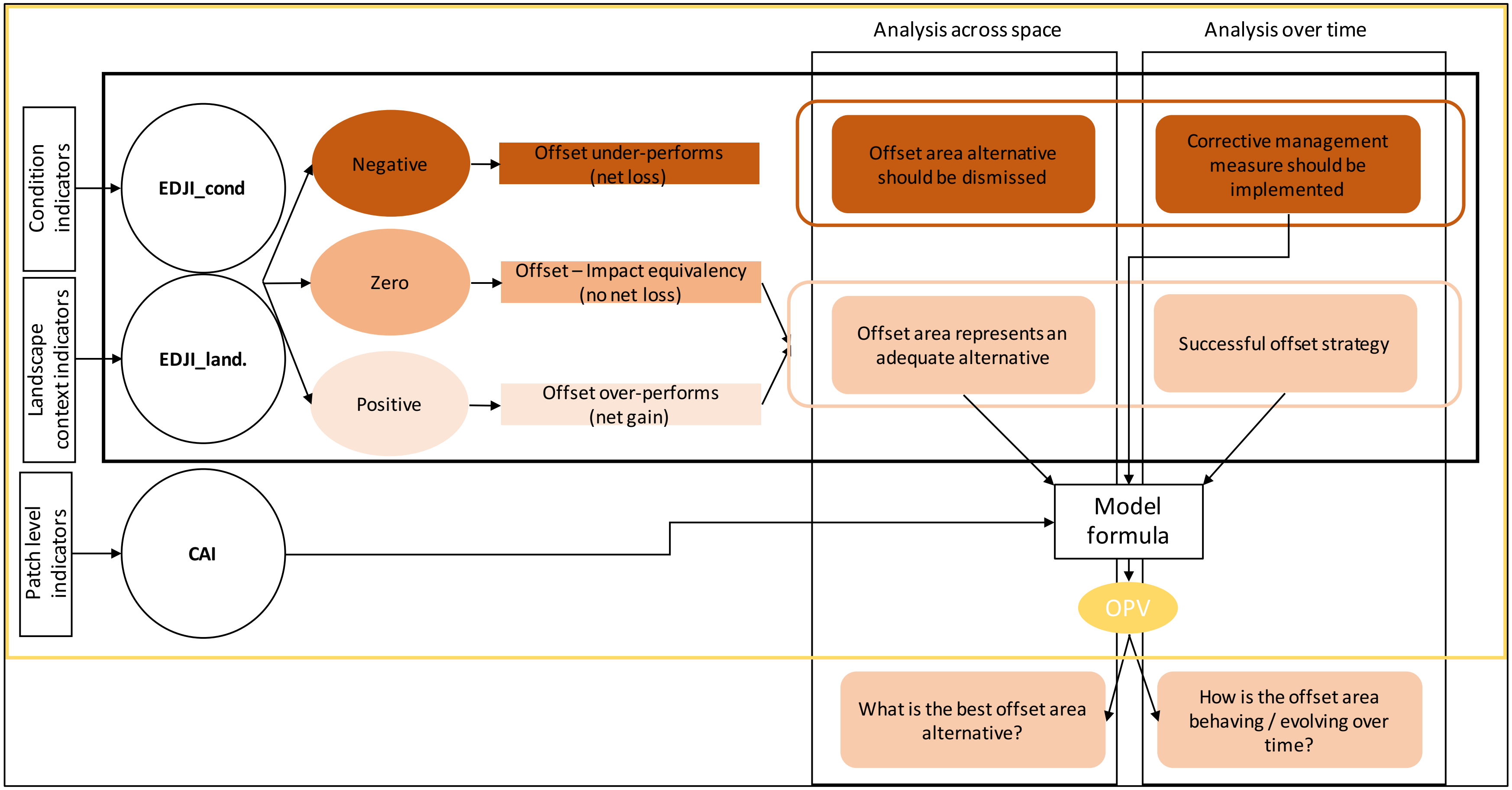

Figure 11 Offset Performance Logic Model process/activities

Key:
EDJI = Ecological Dow Jones Index; OPV = Offset Performance Value; CAI = Core Area Index

Finally, when the arithmetic sum of the results of the indicators in the offset area is equal to the arithmetic sum of the indicator values on the impact area (either for the condition or landscape context criterion), EDJI would equal zero. In this case, the result suggests that the offset area is equivalent to the impact area in one or both criteria, and thus represents an adequate alternative for offsetting the corresponding impacts (in the case of analyses across space). Regarding analyses over time, a no net loss of biodiversity is evidenced and thus the offsetting strategy can be considered successful[24] (see Figure 11).

When the EDJI values for the condition and landscape context criteria are added and multiplied by the offset area's CAI, the OPV is obtained. A final OPV of zero indicates equivalence between impact and offset areas (i.e., no net loss of biodiversity from a landscape perspective). A positive OPV suggests that the offset area over-performs the impact area (i.e., net gain of biodiversity at a landscape scale), while a negative OPV suggests that the offset area under-performs the impact area (i.e., net loss of biodiversity from a landscape perspective).

It should be noted that different offset areas within the same study site boundaries (e.g., same basin or sub-basin), would present equivalent values for the condition and landscape context indicators, as these consist of metrics that are calculated at the class and landscape levels, respectively. In this sense, the EDJI values for both

[24] This, considering BBOP's definition of biodiversity offsets: "Measures taken to compensate for any residual significant, adverse impacts that cannot be avoided, minimised and / or rehabilitated or restored, in order to achieve no net loss or a net gain of biodiversity" (BBOP, 2012, p.1).

criteria would be equivalent, and such areas will only differ in terms of their CAI. In such cases, the final OPV value would only depend on the area's CAI.

Given the uncertainties involved in the offset outcomes, simplifications in measurements, and time lags between the project impact and the offset area achieving its objectives, in order to be confident of achieving no net loss, multipliers[25] are recommended to increase the amount of biodiversity gains required (in this case, the offset core area). The multiplier selected should correspond to the regulations the project is complying with. For example, the largest obligatory multipliers come under South Africa's Western Cape offset policy, requiring compensation of 30 ha of land for every ha cleared in critically endangered habitats (Department of Environmental Affairs and Development Planning [DEADP], 2007).

Besides taking into account existing regulatory multipliers, it is also important to consider the existence of 'special features' in the impact area; these include the presence of threatened/rare species, unique or threatened ecosystems/habitats, relevant ecosystem services, significant concentrations of migratory species, local cultural values, among others. The multiplier selected to assure a no net loss of the mentioned features should ultimately depend on the project's reality, objectives, and impact magnitude.

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[25] Ratio between the amounts of area (negatively) impacted and the area compensated (Laitila, Moilanen, & Pouzols, 2014)

4.3.2. Product P3b – Description of the Offset Performance Logic Model structure as a decision making tool for the implementation and evaluation of biodiversity offsets according to specific model components and offset principles

4.3.2.1. Application of the basic components of logic and conservation models to the Offset Performance Logic Model structure

<u>Components of Logic Models</u>

According to Kellogg (2004), logic models are comprised of five main steps or components that illustrate the connection between the planned work and the intended results: resources/inputs, activities, outputs, outcomes, and impact (Figure 12).

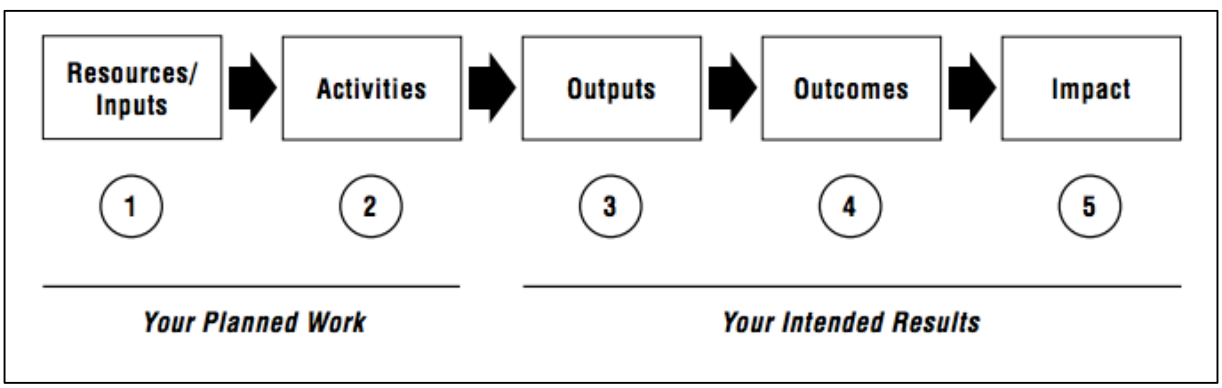

Figure 12 The basic logic model

Source: Kellogg, 2004

Below is a brief description of the components of the logic model applied to the developed Offset Performance Logic Model (OPLM).

- **Planned work:**
  - **Resources/inputs:** resources a program has available to direct towards doing the work. In the OPLM, these consist of the set of potential areas and/or selected offset area being monitored over time.
  - **Activities:** processes, tools, events, technology, and actions that are an intentional part of the program implementation. It involves using the selected indicators to calculate the Offset Performance Value (OPV).
- **Intended results:**
  - **Outputs:** direct products of program activities. In the case of the OPLM, these would consist of the selected offset area, and/or determination of the corrective measures that need to be implemented in such area.
  - **Outcomes:** specific short and long-term changes generated by the program activities. Achieving ecological equivalence between the offset and impact area in the case of the OPLM.
  - **Impacts:** fundamental change occurring as a result of program activities. No net loss of biodiversity would be the ultimate goal or impact of the OPLM.

<u>Components of Conceptual Conservation Models</u>

According to Margoluis, Stem, Salafsky, and Brown (2009), conceptual models differ from logic ones in that the former provides a higher level of detail and precision by attempting to show all of the main forces occurring in the project area, tracing back root causes or driving forces affecting threats and targets, and illustrating the interactions among the identified factors. The different components of a conservation conceptual model, described by Margoluis, Stem, Salafsky, and Brown (2009), can also be applied to the OPLM developed. These are: scope, conservation target, direct threat, contributing factor, strategy, goal, and objective. Below is a brief description of how these components can be applied to the developed model.

- **Scope:** the delimited study area and the different sub-basins defined within it. This varies on a project by project basis. How to delineate the study area and the different sub-basins within it is extremely important, specially considering that offset areas within the same study site boundaries (e.g., same basin or sub-basin), would present equivalent values for the condition and landscape context indicators, as explained before.
- **Conservation target**: ecological systems/ecological communities aggregated into dynamic assemblages or complexes that (1) occur together on the landscape; (2) are linked by ecological processes, underlying environmental features, or environmental gradient; and (3) form a robust, cohesive, and distinguishable unit on the ground.
- **Direct threat**: this depends on the specific project context, and varies on a project by project basis. Considering the principle of 'additionality' (see Subsection 2.2.1), biodiversity offset strategies adopted through conservation activities are only recommended in the cases in which arrested

degradation and/or averted disturbance can be demonstrated, which can be done through counterfactual scenario building (what would have occurred without the intervention). Such counterfactual scenarios respond to the direct threats of the model.

- **Contributing factor:** includes anything influencing, positively and/or negatively, the determined direct threats. Together with the direct threats, this should be determined on a case by case basis.
- **Strategy**: depending on the analysis scenario, this consists of:
    - Conservation/management strategies to be implemented in the offset area in order to achieve no net loss of biodiversity.
    - Corrective measures to be implemented in the offset area (through the process of adaptive management) to make sure no net loss of biodiversity is being achieved through time.
- **Goal:** assure ecological equivalence between the offset and impact areas, and thus achieve the objective of no net loss of biodiversity.
- **Objective:** depending on the analysis scenario, the objective could consist of:
    - Selecting the best offset area alternative in relation to its location in the landscape.
    - Assessing if the offset area is adequately compensating what has been lost over time, in relation to the location of both areas in the landscape.

Appendix E presents a visual representation of how the logic and conservation model components described fit within the OPLM structure.

4.3.2.2. Application of BBOP's principles on biodiversity offsets to the Offset Performance Logic Model structure

According to the BBOP Advisory Group (2012), the following principles need to be met when designing and implementing biodiversity offsets and verifying their success: adherence to the mitigation hierarchy, limits to what can be offset, landscape context, no net loss, additional conservation outcomes, stakeholder participation, equity, long-term outcomes, transparency, science, and traditional knowledge. Below a brief description of the application of such principles to the structure of the Offset Performance Logic Model.

- **Adherence to the mitigation hierarchy:** the OPLM should only be used after appropriate avoidance, minimization and on-site rehabilitation measures have been taken, according to the mitigation hierarchy.
- **Limits to what can be offset**: EDJI values in the OPLM for potential offset areas can be negative, positive, or zero. Negative values suggest that the offset area is under-performing in relation to the impact area, and thus the area does not represent an adequate alternative for offsetting the corresponding impacts from a landscape perspective. If none of the potential offset areas obtain positive (or zero) EDJI values, the impact cannot be offset within the study area being analyzed.

- **Landscape context**: the OPLM explicitly takes into account the landscape context for selecting the best alternative offset area and/or assessing the performance of the selected area over time.
- **No net loss**: no net loss is assessed by measuring the ecological equivalence between the offset and impact areas at a landscape scale.
- **Additional conservation outcomes**: when selecting the set of potential offset areas, the conservation status and/or potential threats over such areas should be considered. A biodiversity offset should achieve conservation outcomes above and beyond results that would have occurred if the offset had not taken place.
- **Stakeholder participation**: because of the way in which the OPLM is structured (through different compartmentalized stages), it facilitates the participation of stakeholders throughout the process.
- **Equity**: because of its compartmentalized structure, the OPLM can be used to explicitly portray the rights and responsibilities, risks, and rewards associated with an offset project of the different stakeholders involved, making sure these are shared in a fair and balanced way.
- **Long-term outcomes:** the OPLM allows the assessment of the selected offset area over time (i.e., monitoring). If it is not adequately compensating what has been lost, then the corresponding corrective measures are easily identified and can be implemented framed under an adaptive management process.

- **Transparency**: According to this principle, the design and implementation of a biodiversity offset, and communication of its results to the public, should be undertaken in a transparent and timely manner. Results can be easily documented and portrayed using the OPLM.
- **Science and traditional knowledge**: the OPLM allows the usage of sound science and traditional knowledge when implementing offsets.

4.4. Step 4: Assessment of existing metrics and use of the Offset Performance Logic Model against the biodiversity offset case study

Step 4 involved the development of two products: P4a, comparison of biodiversity offset requirements and assessment of suitability of potential offset areas using different metrics description of the OPLM and its development process; and P4b, assessment of offset performance across space using the developed OPLM for the selected biodiversity offset case study (BOCS). These two products are outlined in Figure 1 and Table 12, and presented below.

4.4.1. Product P4a – Comparison of biodiversity offset requirements and assessment of suitability of potential offset areas using different metrics

4.4.1.1. Metric selection

Considering that: (1) according to stakeholder's criteria, no net loss should be achieved at an ecosystem or habitat level; (2) there is not an established credit system available for the study area; and (3) there is quantitative information available for the BOCS area; the decision tree (Appendix C) suggests that two potential ‘best fit’ metric options are Habitat Hectares (HH), and Biodiversity Significance Index (BSI). In relation to the indicator desirable properties outlined by Munn (1988) and Noss (1990), the attributes of suitable forms of metrics identified by BBOP (BBOP, 2012), and stakeholders’ criteria, HH and the BSI would be the most suitable metrics for measuring impact losses and offset gains in the biodiversity offset case study (BOCS) area (Appendix B).

4.4.1.2. Calculation of offset requirements using Habitat Hectares

The methodological framework outlined by Parkes, Newell, and Cheal (2003) was followed using a series of steps that involved the analysis of both site condition components (large trees, tree cover, understorey components, cover of weeds, recruitment, organic litter, and logs) and landscape components (patch size, ‘neighborhood’, and distance to core area).

Site condition components

- **Large trees:** This component was not considered, as the offsetting target does not present arboreal vegetation. The habitat score was appropriately standardized according to the benchmark.

- **Tree (canopy) cover:** This component was not considered, as the offsetting target does not present arboreal vegetation. The habitat score was appropriately standardized according to the benchmark.

- **Understorey components:** This assessment includes only indigenous plant species. It is based on a comparison of the life forms present (i.e., groupings of plant species sharing a similar three-dimensional structure and dimensions) between the impact and benchmark areas. Cover and diversity within each life form (i.e., degree of modification) is also considered (Parkes, Newell, & Cheal, 2003).

According to the information presented in the Environmental Impact Assessment (EIA) of the BOCS area (Knight Piésold, 2010), the impact area presents 75% of the life forms present in the benchmark area (Table 17). Of those present, less than 50% are substantially modified in terms of vegetation cover.

Table 17 Vegetation life forms present in the benchmark and impact areas

Vegetation life forms (communities)	Benchmark area	Impact area
Calamagrostis tarmensis - Campylopus cucullatifolius	x	x
Sphagnum magellanicum – Cladina confusa - Loricaria lycopodinea	-	x
Cortaderia hapalotricha - Cortaderia sericantha	x	x
Werneria nubigena – Campylopus spp.	x	x
Carex crinalis - Sphagnum pylaesii	x	x
Plantago tubulosa - Oreobolus obtusangulus - Werneria pygmaea - Distichia acicularis	x	x
Juncus arcticus - Campylopus nivalis	x	x
Carex camptoglochin - Jensenia erythropus	x	-
Carex pichinchensis - Werneria nubigena	x	-

Source: Knight Piésold, 2010

This result corresponds to a value of 15, according to the HH metric (Parkes, Newell, & Cheal, 2003; Table 18).

Table 18 Criteria and scores for the life forms of indigenous understory vegetation present

First decision	Second decision	Value
All strata and lifeforms effectively present		0
Up to 50% of lifeforms present		5
≥ 50–90% of lifeforms present	Of those present ≥ 50% substantially modified	10
	Of those present < 50% substantially modified	15
≥ 90% of lifeforms present	Of those present ≥ 50% substantially modified	15
	Of those present < 50% substantially modified	20
	Of those present, none substantially modified	25

Source: Parkes, Newell, & Cheal, 2003

- **Cover of weeds:** This category includes non-native weed species, as well as native ones that would not normally have occurred within the stand. These are assessed by cover and and the percentage cover of high-threat weed species, considered as such on the basis of invasiveness and direct physical impact for each vegetation type being assessed (Parkes, Newell, and Cheal, 2003).

A thorough literature review of non-native invasive species of Peru was conducted.[26] The list of species obtained was cross-referenced with the list of species reported in the BOCS area, according to the information presented in the project's EIA (Knight Piésold, 2010). A total of 20 invasive flora species (Table 19), was reported, none of which are considered of high-threat.

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[26] Gobierno Regional de Cajamarca, 2009; Ministerio del Ambiente del Peru, n.d.; Tovar, 1993; Vegas, 2009;

Table 19 Invasive flora species reported in the biodiversity offset case study area

Species	High-threat?
Pennisetum clandestinum	No
Rumex acetosella	No
Rumex crispus	No
Dactylis glomerata	No
Trifolium spp.	No
Lolium spp.	No
Avena sp.	No
Cotula australis	No
Rhynchelytrum repens	No
Eucalyptus globulus	No
Opuntia ficu-indica	No
Lantana camara	No
Urtica spp.	No
Plantago major	No
Alnus acuminata	No
Astragalus garbancillo	No
Stipa ichu	No
Parastrephia lepidophylla	No
Taraxacum officinale	No
Festuca ortophylla	No

Since within the impact area the percentage cover of the mentioned species was not significant (<5%), a resultant value of 15 is obtained, according to the HH metric (Parkes, Newell, & Cheal, 2003; Table 20).

Table 20 Criteria and scores for the cover of non-indigenous and native weed plant species present

Weed cover	% of weed cover due to high-threat weeds		
	None	≤ 50%	> 50%
> 50% cover of weeds	4	2	0
25–50% cover of weeds	7	6	4
5–25% cover of weeds	11	9	7
< 5% cover of weeds	15	13	11

Source: Parkes, Newell, & Cheal, 2003

- **Recruitment:** According to Parkes, Newell, and Cheal (2003), given that many species at a site may be ephemeral (e.g., many herbaceous species) and recruitment can be difficult to quantify, this component focuses only on woody perennial species, maintaining like this consistency between assessments. As the offsetting target does not present arboreal vegetation, this component was not considered. The habitat score was appropriately standardized according to the benchmark.

- **Organic Litter:**[27] Most uplands in the *jalca*, *páramo*, and *puna* ecosystems, like the BOCS area, are heavily grazed by domestic livestock and burned annually (Suarez & Medina, 2001). In the case of the BOCS area, plant biomass accumulates and dries on the surface in zones with low stocking densities. This dry biomass is then burned by local people, usually during the dry season, to eliminate it and promote the growth of pasture for cattle grazing (Knight Piésold, 2010). This practice not only affects the superficial biomass being burned, but also all the vegetation formation itself, impacting its recovery capacity, and inducing a process of progressive deterioration. According to Knight Piésold (2010), more than 4% of the land cover of the BOCS area is burned.

  Considering that burned plots lack a protective litter cover, and that pasture burning affect the amount of biomass present, for the purpose of the

[27] Defined as "both fine and coarse plant debris less than 10 cm diameter" by Parkes, Newell, and Cheal (2003).

assessment of this component, I used the presence/absence of burned areas and amount of biomass as a proxy for the amount of organic litter present. According to the agrostology and biomass maps presented in the EIA of the BOCS area (Knight Piésold, 2010), the benchmark and impact areas present the characteristics outlined in Table 21.

Table 21 Benchmark and impact area proxy characteristics for amount of organic litter

Characteristic	Benchmark area	Impact area
Pasture quality	Poor	Poor
Index of bare soil (%)	15.7	16.05
Presence of patches of burned pastures during field evaluation	No	No
Presence of extensive areas of burned pastures within sub-basin reported during field evaluation	No	Yes
Peatland biomass (kg/m^2) - dry season	0.08 - 0.1	0 - 0.05 0.08 - 0.1
Peatland biomass (kg/m^2) - wet season	0.07 - 0.1	0 - 0.06 0.07 - 0.1
Pasture biomass (kg/m^2) - dry season	0.048 - 0.136	0 - 0.016 0.048 - 0.136
Pasture biomass (kg/m^2) - wet season	0.06 - 0.15	0 - 0.03 0.06 - 0.15

Source: Knight Piésold, 2010

As Table 21 indicates, in relation to the benchmark area, the impact area has a slightly higher index of bare soil, lower amount of peatland biomass, and lower amount of pasture biomass. Because of this, the impact area was characterized as having less than 50% of expected litter cover (intermediate level) with native species. This result corresponds to a value of 3 according to the HH metric, (Table 22; Parkes, Newell, & Cheal, 2003).

Table 22 Criteria and scores for the cover of ground level litter present

Litter cover	Litter cover due to native species	
	≤ 50%	> 50%
< 10% of expected cover	0	0
< 50% or > 150% of expected cover	3	2
≥ 50% or ≤ 150% of expected cover	5	4

Source: Parkes, Newell, & Cheal, 2003

- **Logs:** This component was not considered, as the offsetting target does not present arboreal vegetation. The habitat score was appropriately standardized according to the benchmark.

Landscape context components

- **Patch size:** The impact patch has an area of 23.13 ha. Since it is a remnant of native vegetation in a fragmented landscape, it complies with the definition of significantly disturbed of the Regional Forest Agreement Old Growth analyses, where un-natural disturbances have altered the primary attributes of the native vegetation (The State of Victoria Department of Sustainability and Environment, 2004). This corresponds to a value of 8 according to the HH metric (Table 23; Parkes, Newell, & Cheal, 2003).

Table 23 Criteria and scores for the area of the nominated patch

Area	Score
< 2h a	1
≥ 2 but < 5 ha	2
≥ 5 but < 10 ha	4
≥ 10 but < 20 ha	6
≥ 20 ha but significantly disturbed	8
≥ 20 ha but not significantly disturbed *	10

(*) Defined in the Regional Forest Agreement Old Growth analyses.
Source: Parkes, Newell, & Cheal, 2003

- **'Neighbourhood':** This component assesses the degree of both linked and unlinked native vegetation in the 'neighborhood'. A total of three 'neighborhoods' within nested radii (of 100 m, 1 km, 5 km) are scored and summed. The proportion of the area within each radius covered by native vegetation (all the different vegetation cover types different than agriculture, for this analysis) is determined and scored (0.03 weight factor for the 100 m and 5 km radii, and 0.04 weight factor for the 1 km radius). The analysis was done using Geographic Information System (GIS) tools (ArcGIS software). In the case of the impact area, a score of 8.7 was obtained. However, since the majority of the 'neighborhood' is significantly disturbed, two units were subtracted from the score, yielding a final score of 6.7, according to the HH metric (Parkes, Newell, & Cheal, 2003).

- **Distance to core area:** This component involves estimating the distance to the nearest core area, which is defined as "a block of native vegetation greater than 50 ha" (Parkes, Newell, & Cheal, 2003, p. 37). Areas that are part of a vegetation patch greater than 50 ha are considered contiguous, and thus score maximum points. Using ArcGIS software I determined that the impact area is less than 1 km away from a core area (score of 4 units, Table 24. Since the core area is considered significantly disturbed, a final score of 3 was used for this component according to the HH metric (Parkes, Newell, & Cheal, 2003).

Table 24 Criteria and scores for the distance to core area

Distance	Score
> 5km	0
1 – 5 km	2*
< 1km	4*
Contiguous	5*

(*) If core area is significantly disturbed, as defined in Regional Forest Agreement Old Growth analyses, then subtract 1.
Source: Parkes, Newell, & Cheal, 2003

Habitat Hectares final score

The impact area obtained a final standardized habitat score of 72.44%. When multiplied by the site's area (23.13 ha), a total value of 1,675.6 HH units is obtained (Table 25). In order to compensate the future impacts over the impact patch, there is an offset requirement of 1,676.6 HH units.

Table 25 Final Score, Habitat Hectares metric – Impact area

Criteria	Component	Maximum value (%)	Value given
Site condition	Large trees	10	-
	Tree cover	5	-
	Understory strata	25	15
	Lack of weeds	15	15
	Recruitment	10	-
	Organic litter	5	3
	Logs	5	-
Landscape context	Patch size	10	8
	'Neighborhood'	10	6.71
	Distance to core area	5	3
Total		100	50.71
Total standarized			72.44
Habitat hectares units			1675.6

Source: Parkes, Newell, & Cheal, 2003

4.4.1.3. Calculation of offset requirements using the Biodiversity Significance Index

Below I present an outline of the steps followed for calculating offset requirements for the corresponding case study using the Biodiversity Significance Index (BSI) for which the methodological framework outlined by Oliver and Parkes (2003) was followed. According to this metric, a Biodiversity Significance Score (BSS) is determined based on three ppsurrogate measures: Landscape Context (LC), Conservation Significance (CS), and Vegetation Condition (VC), using Equation 3.

Equation 3 Biodiversity Significance Index formula

$$BSI = BSS^{28}\ x\ ha = \frac{(CS + LC) x\ VC}{200}\ x\ ha$$

Where:
BSI = Biodiversity Significance Index
BSS = Biodiversity Significance Score
CS = Conservation Significance
LC = Landscape Context
VC = Vegetation Condition

<u>Landscape Context measure</u>

This metric recognizes that the biodiversity value of a site varies depending on where the site is located in the landscape. It consists of (1) site scale, (2) local scale, and (3) regional scale assessments (Oliver & Parkes, 2003).

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[28] The BSS result is divided by 200 to obtain values that range from 1 to 100 (Oliver and Parkes, 2003).

- **Site scale (30% value):**
  - **Adjacent to an existing remnant**: At least one edge of the impact site is within 10 m of an extant area of native vegetation, so this criterion qualifies for points. The conservation status of the patch was determined using the agrostology map presented in the EIA of the BOCS area, which classifies the vegetation condition of the pastures surrounding the different peatland patches from really poor to good. In the case of the impact patch, it is inmerssed in a matriz of poor quality pastures. This corresponds to a score of 2.

  - **Connects two or more remnants**: At least two separate areas of native vegetation are within 10 m of an edge of the impact site, so this criterion qualifies for points. As before explained, the patch is inmerssed in a matrix of poor quality pastures. This corresponds to a score of 2.

  - **Incorporates a riparian zone**: To qualify for points under this criterion, the site must incorporate an intermittent or permanent watercourse shown on a topographical map of scale 1:50,000. In this case, the impact patch is traversed by a tributary of the Quebrada Chirimayo River. To determine the condition of the riparian zone, the results of the Generic Diatom Generalized Index (GDI) of the area's water bodies were considered (Knight Piésold, 2010). The results obtained in the Quebrada Chirimayo River showed an accentuated eutrophication level, and a regular water quality in 2007, and a minor level of eutrophication, and a good water quality in 2009. Considering these results, the riparian zone can be characterized as having a moderate condition, which corresponds to a score of 4.

- **Contains large trees**: There are no large trees in the peatlands under study. No points were allocated for this component.

- **Has a ratio of area to perimeter greater than 20**: The ratio of area to perimeter of the impact patch is 69, which corresponds to a score of 6.

The final score for the site scale assessment is 14 units, as presented in Table 26.

Table 26 Final score for the site scale assessment

Site scale criteria	Score
Adjacent to existent remnant	2
Connects two or more remnants	2
Incorporates a riparian zone	4
Contains large trees	0
Area to perimeter ratio	6
Total score	14

Source: Oliver & Parkes, 2003

- **Local scale (60% value):**
    - **Patch size:** The impact patch has an area of 23.13 ha. Since it is bigger than 20 ha, the corresponding score is 25.

    - **'Neighborhood':** Three nested 'neighborhoods' were assessed, based on the area of native vegetation, as a proportion of the total area, within each 'neighbourhood'. This analysis was done using GIS, considering all vegetation cover, besides agriculture, as native. The impact patch obtained a final score of 24.

    - **Distance to core area:** estimation of the distance to the nearest large patch of native vegetation, greater than 50 ha. The impact patch is contiguos to a large patch of pasture, and therefore the obtained score corresponds to 10.

The final score for the local scale assessment is 59 units, as presented in Table 27.

Table 27 Final score for the site scale assessment

Local scale criteria	Score
Patch size	25
'Neighborhood'	24
Distance to core area	10
Total score	59

Source: Oliver & Parkes, 2003

- **Regional scale (10% value):**

  At this scale, landscape context aims to prioritize areas such as regional corridors from the aspect of biodiversity conservation. The BOCS area does not have any type of designation or importance status; there are no National Protected Areas within it, RAMSAR wetlands, or Important Bird Areas (IBAs). Because of this, it was considered as low priority for biodiversity conservation, and thus a score of 3 was allocated, which corresponds to a weighted score of 0.3.

The final score of the Landscape Context (LC) surrogate measure was calculated as: LC = 14 + 59 + 3 = 76 units.

<u>Conservation Significance measure</u>

Since Conservation Significance (CS) categorization is not available for the BOCS area, it was estimated using the guidelines provided by Oliver and Parkes (2003), and the information included in the biological baseline of the site's EIA (Knight Piésold, 2010). The conservation significance category of a particular vegetation type is determined based on the assessment of the following criteria: (1) decline in its pre-clearing geographic distribution, (2) current rate of detrimental change, and (3) time frame of regional extinction if threatening processes remains unchanged. The vegetation type receives the highest CS category allocated among the three mentioned criteria.

- **Decline in its pre-clearing geographic distribution:** For this assessment I focused on the impact patch, using it as a proxy for estimating the decline of peatlands in the region. Figure 13 shows the extent of the impact patch in 2010, obtained from the project's EIA (Knight Piésold, 2010), and in 1969, obtained from Google Earth satellite images. During a 41 year period, the extent of the impact patch has decreased by almost 50% (from 44.6 ha in 1969 to 23.13 ha in 2010). According to Oliver and Parkes (2003), this corresponds to a Conservation Significance category of Near Threatened**.**

Figure 13 Extent of peatland impact patch in 1969 and 2010
Key:
Colors: Orange = peatland extent in 2010; green = peatland extent in 1969.
Sources: Knight Piésold, 2010; Google Earth.

- **Current rate of detrimental change:** According to Maldonado (2014), main threats to the peatlands of the BOCS area include: overgrazing, peat extraction, mining, and development of infrastructure (e.g., roads).
  - **Overgrazing:** All Peruvian peatlands are probably being grazed and/or have been grazed in the past, and are thus continuously subject to external pressure (Maldonado, 2014). At present, *puna* peatlands show patterns of excessive stocking and consequent overgrazing especially due to the high density of alpaca and sheep (Lara 2003).
  - **Peat extraction**: The cutting of peat for use as a fuel for cooking creates high impact over a short time period. The natural regeneration of cutover peatlands is slow and difficult under the prevailing climatic conditions, especially because their vegetation has been removed.
  - **Mining:** According to the Peruvian Environmental Regulations for Mining Exploration Activities (DS 20-2008-EM, Article 11): "no exploration activity or roads may cross peatlands or wetlands, or cause placement of materials, waste or any other matter or substance on them." However, this is not the case for exploration activities, which can be developed in peatland areas.

Besides these impacts, it is important to consider the large period of time required for peat to grow and accumulate after the vegetation formation has been impacted. For example, in Chilean Andes, the rate of peat accumulation is approximately 1 m per 1000 years, which is considered relatively fast (Earle, Warner, & Aravena, 2003). Considering that there is no evidence suggesting that the described impacts and threats are decreasing, and taking into account the slow regeneration rate of this type of vegetation formation, the suspected rate of detrimental change was estimated to be at least 50% for the immediate future. This qualifies as a severe rate of detrimental change, and corresponds to the Endangered Conservation Significance category (Oliver & Parkes, 2003).

- **Time frame of regional extinction if threatening processes remain unchanged**: According to the study of the vegetation composition of the peatlands present in the BOCS area, the species found within the largest number of stands evaluated, and with the largest vegetation cover, are *Werneria nubigena* and *Calamagrostis tarmesis*. *W. nubigena* has a relatively wide distribution throughout Central America (reports include Mexico and Guatemala) and the Andes, from Colombia to Bolivia, usually between 2,800 and 4,000 m of elevation. In Peru, it has been reported in the following departments: Ancash, Amazonas, Apurímac, Cajamarca, Cusco, Junín, Lambayeque, Lima, La Libertad San Martín, and Piura (Salvador, Alonso, & Rios, 2006). *C. tarmensis's* distribution is similar to that of *W. nubigena*, expanding south to Argentina. In Peru, it has been reported in the departments of: Ancash, Cajamarca, Cusco, Huánuco, Huancavelica, Junín, La Libertad, and Pasco, usually at elevations between about 3,000 and 4,000 m (Tovar, 1993).

Neither of these species is considered vulnerable or have a conservation category (national or international), and both are well represented throughout their distributions. They can grow under harsh conditions, and do not have particular or specific requirements to develop. Hence, it is not expected that these species will go extinct even if threatening processes remain unchanged. The applicable potential CS categories in this case range from Vulnerable (medium-term, 50 years), to Near Threatened (long-term, 100 years) and Least Concern (very long-term, 500 years), (Oliver and Parkes, 2003).

The highest CS category allocated among the three mentioned criteria corresponds to Endangered**.** The score of this category is 80 units (LC = 80).

Vegetation Condition measure

The different attributes analyzed for this component, and their corresponding values (which add to a maximum of 100), are presented in Table 28.

Table 28 Vegetation Condition attributes and values

Attributes		Value (%)
Richness of benchmarked plant groups		25
Cover of benchmarked plant groups		20
Cover or density of:	Recruitment	10
	Weeds	15
	Organic litter	5
	Large trees	15
	Hallow-bearing trees	5
	Wood load	5
TOTAL		100

Source: Oliver & Neal, 2003

The assessment of vegetation condition requires a Vegetation Condition Benchmark (VCB), that provides a range of values for vegetation considered to be in very poor, poor, moderate, high, and very high condition. Since a VCB does not exist for the BOCS area, a preliminary hypothetical one was developed, considering the benchmark patch identified in Subsection 3.4.1. The benchmarked plant groups within the VCB are presented in Table 29.

Table 29 Description of Vegetation Condition Benchmarked groups

VCB group	Description
Cushion plants	In the VCB, most common cushion forming species are *Werneria nubigena, W. pygmaea, Plantago tubulosa, Oreobolus obtusangulus*, and *Distichia acicularis*
Sedges and rushes	Sedge and rush dominated communities occur on the edges of all large lakes and ponds in the study area, where seasonal standing water occurs in small pools, or where sheet flow occurs. In the VCB, these are dominated by *Carex* spp. and *Juncus arcticus*
Bryophytes and lichens	Bryophyte communities occur on slightly raised ground adjacent to pools where the water table reaches the soil surface, and the lichens appear to occur in areas where the ground is rarely flooded. In the VCB, bryophyte communities are dominated by species of the *Campylopus, Sphagnum*, and *Jensenia* genera
Tufted or tussock grasses	Communities dominated by tufted, or tussock, grasses, mainly belonging to the *Calamagrostis* and *Cortaderia* genera

Key:
VCB = Vegetation Condition Benchmark
Source: Knight Piésold, 2010

- **Richness of benchmarked plant groups (value 25%):** For the assessment of this attribute, the richness of native plants in the impact area was estimated for the four plant groups in Table 29, and compared with the richness benchmarks per group of the VCB (Table 30). Table 31 was constructed using the information presented in the EIA of the BOCS area (Knight Piésold, 2010). The final score obtained for this attribute corresponds to 18.75.

Table 30 Richness benchmarks for the VCB

Condition class	**Very low**	**Low**	**Moderate**	**High**	**Very high**
Condition score	**5**	**10**	**15**	**20**	**25**
Cushion plants	0	1	2-3	4-5	>5
Sedges and rushes	0	1	2	3-4	>4
Bryophytes and lichens	0	1	2-3	4-5	>5
Tufted or tussock grasses	0	1	2	3	>3

Source: Knight Piésold, 2010

Table 31 Calculation of richness score for impact area

Condition class		**Very low**	**Low**	**Moderate**	**High**	**Very high**	**Score**
Condition score		**5**	**10**	**15**	**20**	**25**	
Cushion plants	VCB	1	2	3-4	5	>5	
	Impact				5		20
Sedges and rushes	VCB	1	2	3	4	>4	
	Impact		2				10
Bryophytes and lichens	VCB	1	2	3-4	5	>5	
	Impact					7	25
Tufted or tussock grasses	VCB	1	1	2	3	>3	
	Impact				3		20
Total							75
Total richness score (Total/4)							18.75

Key:
VCB = Vegetation Condition Benchmark
Source: Knight Piésold, 2010

- **Cover of benchmarked plant groups (value 20%):** Cover of benchmarked plant groups is assessed in the same way as richness, but against the cover benchmark for each plant group. In this case, the bryophytes and lichens group was not considered, as there was no data available of the percentage cover of the corresponding species on the BOCS area. Table 32 presents the estimate of percentage cover per plant group in the benchmark area and Table 33 the scoring results of the impact area. Tables were constructed using the information presented in the EIA of the BOCS area (Knight Piésold, 2010). The final score obtained for this attribute corresponds to 6.67.

Table 32 Cover benchmarks for the Vegetation Condition Benchmark

Condition class	Very low	low	Moderate	High	Very high
Condition score	**4**	**8**	**12**	**16**	**20**
Cushion plants	<7	7-26	26-45	45-63	>63
Sedges and rushes	<16	16-21	21-26	26-31	>31
Bryophytes and lichens	-	-	-	-	-
Tufted or tussock grasses	<45	45-51	51-57	57-63	>63

Source: Knight Piésold, 2010

Table 33 Calculation of cover score for impact area

Condition class		Very low	low	Moderate	High	Very High	Score
Condition score		**4**	**8**	**12**	**16**	**20**	
Cushion plants	VCB	<7	7-26	26-45	45-63	>63	
	Impact			28			12
Sedges and rushes	VCB	<16	16-21	21-26	26-31	>31	
	Impact	7					4
Bryophytes and lichens	-	-	-	-	-	-	-
Tufted or tussock grasses	VCB	<45	45-51	51-57	57-63	>63	
	Impact	29					4
Total							20
Total coverage score (Total/3)							6.67

Key:
VCB = Vegetation Condition Benchmark
Source: Knight Piésold, 2010

- **Cover or density of recruitment (value 10%):** This assessment is focused upon woody perennial species, which are limited to trees and shrubs. As the offsetting target does not present arboreal vegetation, the component was not considered. Because of this, the final score was appropriately adjusted considering the percentage values presented in Table 28, removing the corresponding 10% value from the highest posible total score (see Table 36).

- **Cover or density of weeds (value 15%):** As in the case of the Habitat Hectares (HH) metric, assessment is based on the cover of weed species and also the threat posed due to invasiveness. The results correspond to those obtained for the weed cover component, of the HH metric (Subsection 4.4.1.2). The impact area presents a weed cover of less than 5%, with no species being considered as of high-threat. This corresponds to a final score of 15 for this attribute (Table 34).

Table 34 Weed cover categories and score for impact area

Weed cover (%)	**Proportion of weed cover represented by high-threat weed species**		
	None	**< 50%**	**> 50%**
> 50	3	1	0
25-50	7	5	3
5-25	11	9	7
< 5	15	13	11

Source: Oliver & Neal, 2003

- **Cover or density of organic litter (value 5%):** As indicated for the organic litter component of the HH metric, the impact area has a slightly higher index of bare soil, lower amount of peatland biomass, and lower amount of pasture biomass, in relation to the benchmark area. Because of this, the impact area was characterized as having between 10 and 50% of expected litter cover. This result corresponds to a value of 3 according to the BSS guidelines (considering a depth of litter of more than 1 cm; Table 35).

Table 35 Density of organic litter categories and score for impact area

Organic litter cover (percentage of benchmark litter cover) (%)	**Depth of litter (cm)**	
	< 1	**> 1**
< 10	0	1
10-50	2	3
≥ 50	4	5

Source: Oliver & Neal, 2003

- **Cover or density of large trees (value 15%):** As the offsetting target does not present arboreal vegetation, the component was not considered. Because of this, the final score was appropriately adjusted considering the percentage values presented in Table 28, removing the corresponding 15% value from the highest posible total score (see Table 36).

- **Cover or density of hollow-bearing trees (value 5%):** As the offsetting target does not present arboreal vegetation, the component was not considered. Because of this, the final score was appropriately adjusted considering the percentage values presented in Table 28, removing the corresponding 5% value from the highest posible total score (Table 36).

- **Cover or density of wood load (value 5%):** As the offsetting target does not present arboreal vegetation, the component was not considered. Because of this, the final score was appropriately adjusted considering the percentage values presented in Table 28, removing the corresponding 5% value from the highest posible total score (Table 36).

Table 36 presents the final score of the Vegetation Condition (VC) surrogate measure for the impact area.

Table 36 Final score of Vegetation Condition surrogate measure for the impact area (Biodiversity Significance Score)

Attribute	Value (%)	Score obtained
Richness of benchmarked plant groups	25	18.75
Cover of benchmarked plant groups	20	6.67
Recruitment cover	10	-
Weed cover	15	15
Organic litter cover	5	3
Cover of large trees	15	-
Cover of hollow-bearing trees	5	-
Wood load cover	5	-
Total	100	43.42
Standardized total score		68.9

Source: Oliver & Neal, 2003

Biodiversity Significance Index final score

The final result of the Biodiversity Significance Index (BSI) for the impact area was calculated by multiplying the site’s area (23.13 ha) by its Biodiversity Significance Score (BSS, 53.7 units), as indicated in Equation 4. A final value of 1,243 is obtained, which corresponds to the total amount of BSI units required to compensate the future impacts over the impact patch.

Equation 4 Calculation of the BSI for the impact area of the BOCS

$$BSI = BSS\ x\ ha = \frac{(CS + LC) x\ VC}{200}\ x\ ha = \frac{(80 + 76) x\ 68.9}{200}\ x\ 23.13 = 53.7\ x\ 23.13 = 1243$$

Where:
BSI = Biodiversity Significance Index
BSS = Biodiversity Significance Score
CS = Conservation Significance
LC = Landscape Context
VC = Vegetation Condition

4.4.1.4. Assessment of potential offset areas in terms of the identified offset requirements

The five potential offset areas identified in Subsection 3.4.1.3 were analyzed using both metrics, HH and BSI, to determine how well they satisfy the calculated offset requirements. The results are presented in Tables 37 and 38.

Table 37 Final Score, Habitat Hectares (HH) metric – potential offset areas

Criteria	Component	Max. value (%)	Habitat score per potential offset area				
			Offset A	Offset B	Offset C	Offset D	Offset E
Site condition	Large trees	10	-	-	-	-	-
	Tree cover	5	-	-	-	-	-
	Understory strata	25	0	15	5	5	5
	Lack of weeds	15	15	15	11	15	15
	Recruitment	10	-	-	-	-	-
	Organic litter	5	5	5	5	3	5
	Logs	5	-	-	-	-	-
Landscape context	Patch size	10	1	6	4	8	2
	'Neighborhood'	10	7.79	6.52	7.11	7.32	7.55
	Core area distance	5	3	3	3	3	3
Total			31.79	50.52	35.11	41.32	37.55
Total standardized			45.41	72.17	50.16	59.03	53.64
Area (ha)			0.81	16.87	7.51	23.1	2.9
Habitat Hectares units			36.79	1217.53	376.68	1363.56	155.56

Key:
Areas: Offset A = Chailhuagón sub-basin; Offset B = Alto Jadibamba sub-basin; Offset C = Toromacho sub-basin; Offset D = Alto Chirimayo sub-basin; and Offset E = Chugurmayo sub-basin (see Subsection 3.4.1)

Table 38 Final Score, Biodiversity Significance Index (BSI) metric – potential offset areas

Measure	**Component**	**Potential offset areas**				
		Offset A	**Offset B**	**Offset C**	**Offset D**	**Offset E**
CS	Total CS score	80	80	80	80	80
LC	Site scale (30%)	2	16	12	18	24
	Local scale (60%)	31.1	54.6	47.5	58.4	43.9
	Regional scale (10%)	3	3	3	3	3
	Total LC score	36.1	73.6	62.5	79.4	70.9
VC	Richness of benchmarked plant groups (25%)	2.5	16.25	10	11.25	15
	Cover of benchmarked plant groups (20%)	8.0	5.3	5.3	1.3	5.3
	Recruitment (10%)	-	-	-	-	-
	Weeds (15%)	15	15	11	15	15
	Organic litter (05%)	5	5	5	3	5
	Large trees (15%)	-	-	-	-	-
	Hollow-bearing trees (05%)	-	-	-	-	-
	Wood load (05%)	-	-	-	-	-
	Total VC score	30.5	41.6	31.3	30.6	40.3
	Total standardized VC score	46.9	64.0	48.2	47.1	62.1
Biodiversity Significance Score		27.2	49.1	34.4	37.5	46.8
Area (ha)		0.81	16.87	7.51	23.1	2.9
Biodiversity Significance Index units		22.1	828.8	258.0	866.1	135.8

Key:
Measures: CS = Conservation Significance; LC = Landscape Context; VC = Vegetation Condition
Areas: Offset A = Chailhuagón sub-basin; Offset B = Alto Jadibamba sub-basin; Offset C = Toromacho sub-basin; Offset D = Alto Chirimayo sub-basin; and Offset E = Chugurmayo sub-basin (see Subsection 3.4.1.)

From Tables 37 and 38 it can be concluded that both metrics, HH and BSI, yield equivalent results in terms of the adequacy of the different potential offset areas to meet the offset requirements. In both cases, Offset A (Chailhuagón sub-basin) is characterized as the least qualified area, followed by Offsets E, C, and B; both metrics characterize Offset D (Alto Chirimayo sub-basin) as the most qualified area.

These results suggest that the two metrics considered have a similar behavior when accounting for losses and gains for projects with similar characteristics as the selected BOCS. In this case, impact losses and offset gain calculations are not dependent on the type of metric being used. However, none of the potential offset areas alone will adequately offset the expected impacts on the impact area (Figure 14).

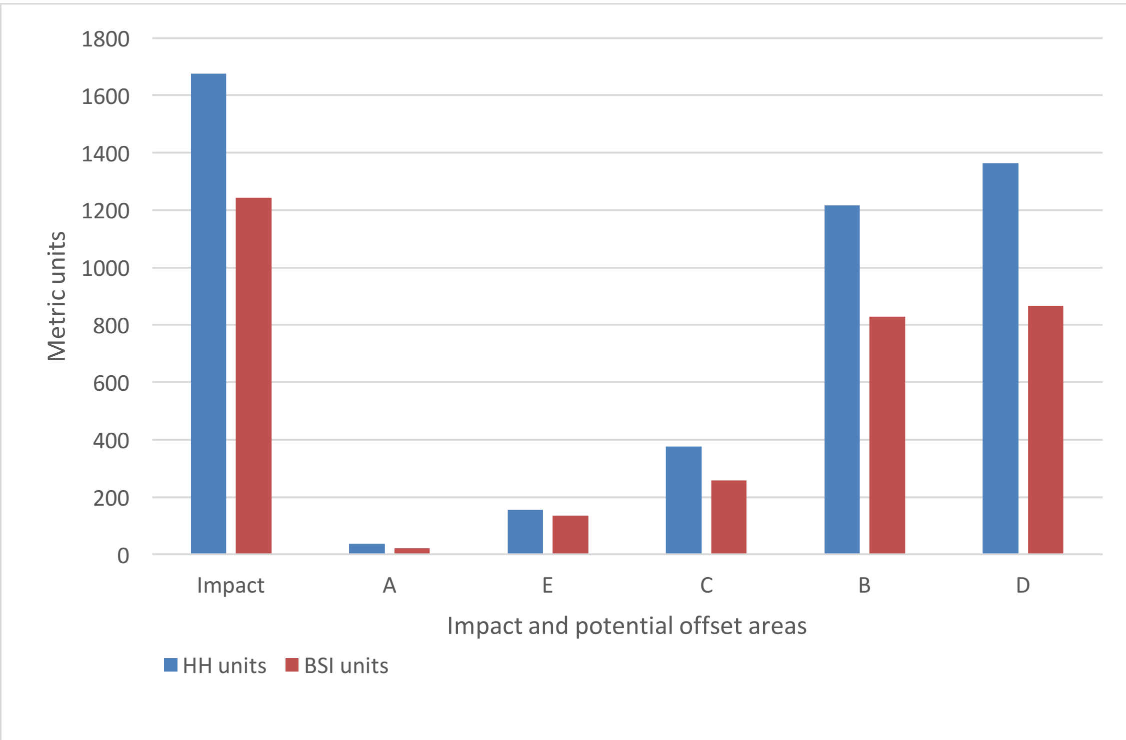

Figure 14 Final Habitat Hectares (HH) and Biodiversity Significance Index (BSI) scores for the impact and potential offset areas

Key:
Metrics: HH = Habitat Hectares and BSI = Biodiversity Significance Index
Areas: Offset A = Chailhuagón sub-basin; Offset B = Alto Jadibamba sub-basin; Offset C = Toromacho sub-basin; Offset D = Alto Chirimayo sub-basin; and Offset E = Chugurmayo sub-basin (see Subsection 3.4.1)

Considering that none of the potential offset areas alone will adequately offset the expected impacts, the alternative solutions would be to either (1) identify and analyze additional offset areas, or (2) construct a portfolio of offset sites (from those already analyzed) that together offset the corresponding impacts. Pursuing the first alternative would be costly in time and financial requirements. Considering the second alternative, the following alternative portfolios[29] would be adequate to offset the corresponding impacts according to both the HH and BSI metrics (Table 39).

- Portfolio 1: B+D
- Portfolio 2: B+D+C
- Portfolio 3: B+D+E
- Portfolio 4: B+D+A
- Portfolio 5: D+C+E

4.4.2. Product P4b - Assessment of offset performance across space using the developed Offset Performance Logic Model for the selected Biodiversity Offset Case Study

Below I present an outline of the steps followed for assessing the performance of the potential offset areas in terms of their location within the landscape in relation to the impact area (Application 1, see Subsection 3.3), through the use of the Offset Performance Logic Model.[30] This was done following the process of a logic model, as detailed in Subsection 4.3.2.1.

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[29] A maximum of three areas were considered per portfolio, for practical purposes.
[30] As noted, the OPLM is used as a further step to evaluate the suitability of potential offset areas to compensate the corresponding impacts within a landscape context.

Table 39 Portfolios of offset areas with the potential of offsetting expected impact

Offset area or offset portfolio	Offset potential per offset area/portfolio		Offset requirements (impact area)		The offset area/portfolio has the potential to offset the expected impacts?	
	HH	BSI	HH	BSI	HH	BSI
Offset A	36.79	22.1	1676.6	1243	No	No
Offset B	1217.53	828.8			No	No
Offset C	376.68	258			No	No
Offset D	1363.56	866.1			No	No
Offset E	155.56	135.8			No	No
Portfolio 1: B + D	2581.09	1694.9			Yes	Yes
Portfolio 2: B + D + C	2957.77	1952.9			Yes	Yes
Portfolio 3: B+D+E	2736.65	1830.7			Yes	Yes
Portfolio 4: B+D+A	2617.88	1717			Yes	Yes
Portfolio 5: D+C+E	1895.8	1259.9			Yes	Yes

Key:
Metrics: HH = Habitat Hectares and BSI = Biodiversity Significance Index
Areas: Offset A = Chailhuagón sub-basin; Offset B = Alto Jadibamba sub-basin; Offset C = Toromacho sub-basin; Offset D = Alto Chirimayo sub-basin; and Offset E = Chugurmayo sub-basin (see Subsection 3.4.1)

4.4.2.1. Offset Performance Logic Model inputs

As indicated in Subsection 4.4.1.4, none of the five potential offset areas considered (A through E), on its own, will be adequate to offset the expected impacts on the impact area, so alternative portfolios of offset areas, which in conjunction are able to offset the corresponding impacts, were constructed. These potential portfolios correspond to the OPLM inputs.[31]

4.4.2.2. Offset Performance Logic Model activities

The OPLM activities (for this particular case) involves determining the best potential portfolio of offset areas; this, in terms of the location of each area within

[31] Even though the inputs consist of potential sets of offset areas, the OPLM analyzes each area separately and delivers individual results.

the landscape, in relation to the impact area. This is determined through the calculation of the OPV, which involves (1) calculating landscape indicators, (2) building a ranking system, and (3) scoring the offsetting targets.

Calculation of landscape indicators

The potential offset areas, as well as the impact and benchmark areas were characterized using the landscape indicators presented in Appendix D. Indicators were calculated for each of the three types of areas (impact, benchmark, and offset) using FRAGSTATS. The land cover raster images required for this analysis were generated from land cover shape files of the BOCS area using ArcGIS. Such land cover shape files, in turn, were digitized using the information provided in the area's EIA (Knight Piésold, 2010). The results obtained are presented in Table 40.

Scoring of offsetting target – building a ranking system

For the condition and landscape context indicators, the ranking system was built using the minimum and maximum possible values that each indicator can yield, classified as representing either the 'best' or 'worst' possible results. Regarding the CLUMPY index, for example, possible values range from '-1' to '1'. The first value corresponds to the maximum disaggregation of patches ('worst' scenario), while the second to the maximum aggregation of patches ('best' scenario), (Table 41).[32]

[32] Indicators are described in Table 16, Subsection 6.3.1.3. The Core Area Index, under the size criterion, is evaluated independently, and later on incorporated in the final OPV calculation. There is no need for a ranking system in this case. For those indicators that do not have an established possible extreme value (e.g., SPLIT, SHDI, and GYRATE_AM), the lowest/highest of the results obtained in each of the evaluated areas was considered.

Table 40 Results of the landscape indicators considered within the OPLM for each type of area

<table>
<tr><th rowspan="3">Criteria</th><th rowspan="3">Metric level</th><th rowspan="3">Indicator</th><th colspan="7">Areas</th></tr>
<tr><th rowspan="2">B</th><th rowspan="2">I</th><th colspan="5">Offset areas</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th></tr>
<tr><td>Size</td><td>Patch</td><td>CAI</td><td>-</td><td>47.8</td><td>57.7</td><td>47.5</td><td>29.0</td><td>49.4</td><td>16.7</td></tr>
<tr><td rowspan="6">Condition</td><td rowspan="4">Class</td><td>CLUMPY</td><td>0.5</td><td>0.7</td><td>0.6</td><td>0.5</td><td>0.7</td><td>0.7</td><td>0.5</td></tr>
<tr><td>IJI</td><td>13.9</td><td>31.8</td><td>35.8</td><td>24.2</td><td>64.7</td><td>35.7</td><td>13.9</td></tr>
<tr><td>ED</td><td>2.1</td><td>3.1</td><td>4.6</td><td>6.2</td><td>1.4</td><td>2.6</td><td>2.1</td></tr>
<tr><td>CONNECT</td><td>1.7</td><td>1.4</td><td>0.5</td><td>0.6</td><td>0.0</td><td>1.6</td><td>1.7</td></tr>
<tr><td rowspan="4">Landscape</td><td>SPLIT (thousands)</td><td>316.8</td><td>45.1</td><td>98.7</td><td>53.3</td><td>209.2</td><td>84.9</td><td>316.8</td></tr>
<tr><td>SHDI</td><td>1.2</td><td>1.2</td><td>1.0</td><td>0.5</td><td>1.0</td><td>1.2</td><td>1.2</td></tr>
<tr><td rowspan="2">Landscape context</td><td>PAFRAC</td><td>1.5</td><td>1.6</td><td>1.5</td><td>1.5</td><td>1.6</td><td>1.6</td><td>1.5</td></tr>
<tr><td>GYRATE_AM (thousands)</td><td>1.5</td><td>1.8</td><td>2.2</td><td>2.8</td><td>2.0</td><td>1.8</td><td>1.5</td></tr>
</table>

Key:
Areas: B = benchmark area; I = impact area; Offset A = Chailhuagón sub-basin; Offset B = Alto Jadibamba sub-basin; Offset C = Toromacho sub-basin; Offset D = Alto Chirimayo sub-basin; and Offset E = Chugurmayo sub-basin (see Subsection 3.4.1)
Indicators: CAI = Core Area Index; CLUMPY = Clumpiness Index; CONNECT = Connectance Index; ED = Edge Density Index; GYRATE_AM = Correlation Length Index; IJI = Interspersion/Juxtaposition Index; PAFRAC = Perimeter-Area Fractal Dimension Index; SHDI = Shannon's Diversity Index; and SPLIT = Splitting Index (see Table 16, Subsection 4.3.1.3)

Table 41 'Best' and 'worst' possible scenarios of selected indicators

Indicator	Extreme possible results	
	'Best' Scenario	'Worst' Scenario
CLUMPY	1	-1
IJI	0	100
ED	0	6.2
CONNECT	100	0
SPLIT (thousands)	1	316.8
SHDI	1.2	0
PAFRAC	2	1
GYRATE_AM (thousands)	2.8	0

Key:
Indicators: CAI = Core Area Index; CLUMPY = Clumpiness Index; CONNECT = Connectance Index; ED = Edge Density Index; GYRATE_AM = Correlation Length Index; IJI = Interspersion/Juxtaposition Index; PAFRAC = Perimeter-Area Fractal Dimension Index; SHDI = Shannon's Diversity Index; and SPLIT = Splitting Index (see Table 16, Subsection 4.3.1.3)

All of the obtained results were organized in sets per offset area. Each set presented the results for a specific potential offset area, the results for the impact and benchmark areas, and the 'best' and 'worst' possible values presented in Table 41. The results of the condition and landscape context indicators of each set were normalized (Table 42).

Table 42 Normalized results per indicator per area

Criteria	Indicator	Areas						
		B	I	Offset areas				
				A	B	C	D	E
Size	CAI	-	-	-	-	-	-	-
Condition	CLUMPY	0.8	0.9	0.8	0.8	0.8	0.8	0.8
	IJI	0.9	0.7	0.6	0.8	0.4	0.6	0.9
	ED	0.7	0.5	0.3	0.0	0.8	0.6	0.7
	CONNECT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SPLIT	0.0	0.9	0.7	0.8	0.3	0.7	0.0
	SHDI	1.0	1.0	0.9	0.4	0.8	1.0	1.0
Landscape context	PAFRAC	0.5	0.6	0.5	0.5	1.6	0.6	0.5
	GYRATE_AM	0.5	0.6	0.8	1.0	0.7	0.6	0.5

Key:
Areas: B = benchmark area; I = impact area; Offset A = Chailhuagón sub-basin; Offset B = Alto Jadibamba sub-basin; Offset C = Toromacho sub-basin; Offset D = Alto Chirimayo sub-basin; and Offset E = Chugurmayo sub-basin (see Subsection 3.4.1)
Indicators: CAI = Core Area Index; CLUMPY = Clumpiness Index; CONNECT = Connectance Index; ED = Edge Density Index; GYRATE_AM = Correlation Length Index; IJI = Interspersion/Juxtaposition Index; PAFRAC = Perimeter-Area Fractal Dimension Index; SHDI = Shannon's Diversity Index; and SPLIT = Splitting Index (see Table 16, Subsection 4.3.1.3)

Calculation of Offset Performance Values

The Offset Performance Value (OPV) for the potential offset areas was calculated using the Equation 2 presented in Subsection 4.4.2.2. Table 43 presents the different calculations made, and Figure 15 the final OPV results per offset area. Figure 15 indicates that Offset C (Toromacho sub-basin) is the only option yielding positive Offset Performance Values, suggesting that this area over-performs in relation to the impact site from a landscape perspective. The other offset areas all yield negative OPVs, which suggest that these areas under-perform in relation to the impact site considering their location within the landscape.

Table 43 Calculation of Offset Performance Values per potential offset area

Item of OPV formula	Area					
	I	Offset A	Offset B	Offset C	Offset D	Offset E
CAI…..(i)	-	58	48	29	49	17
$\left(\sum_{i=1}^{6} C.Ii\right)$	3.9	-	-	-	-	-
$\left(\sum_{i=1}^{6} C.Oi\right)$	-	3.3	2.8	3.1	3.8	3.3
$\frac{(\sum_{i=1}^{6} C.Oi)-(\sum_{i=1}^{6} C.Ii)}{(\sum_{i=1}^{6} C.Ii)} \times 100$.....(ii)	-	-15.8	-27.3	-19.6	-2.9	-15.3
$\sum_{i=1}^{2} L.Ii$	1.2	-	-	-	-	-
$\sum_{i=1}^{2} L.Oi$	-	1.3	1.5	2.3	1.2	1.1
$\frac{(\sum_{i=1}^{2} L.Oi)-(\sum_{i=1}^{2} L.Ii)}{(\sum_{i=1}^{2} L.Ii)} \times 100$…..(iii)	-	9.2	24.7	88.3	0.3	-10.3
(ii) + (iii)	-	-6.6	-2.6	68.7	-2.6	-25.6
OPV = (i) x [(ii) + (iii)]	-	-381.4	-125.2	1994.3	-127.9	-425.9

Key:
Areas: I = impact area; Offset A = Chailhuagón sub-basin; Offset B = Alto Jadibamba sub-basin; Offset C = Toromacho sub-basin; Offset D = Alto Chirimayo sub-basin; and Offset E = Chugurmayo sub-basin (see Subsection 3.4.1)
OPV = Offset Performance Value
OPV formula: CAI = Core Area Index; C.O = normalized values of indicators selected for the condition criterion, in the offset area; C.I = normalized values of indicators selected for the condition criterion, in the impact area; L.I = normalized values of indicators selected for the landscape context criterion, in the impact area; L.O = normalized values of indicators selected for the landscape context criterion, in the offset area (see Equation 2, Subsection 4.3.1.3)

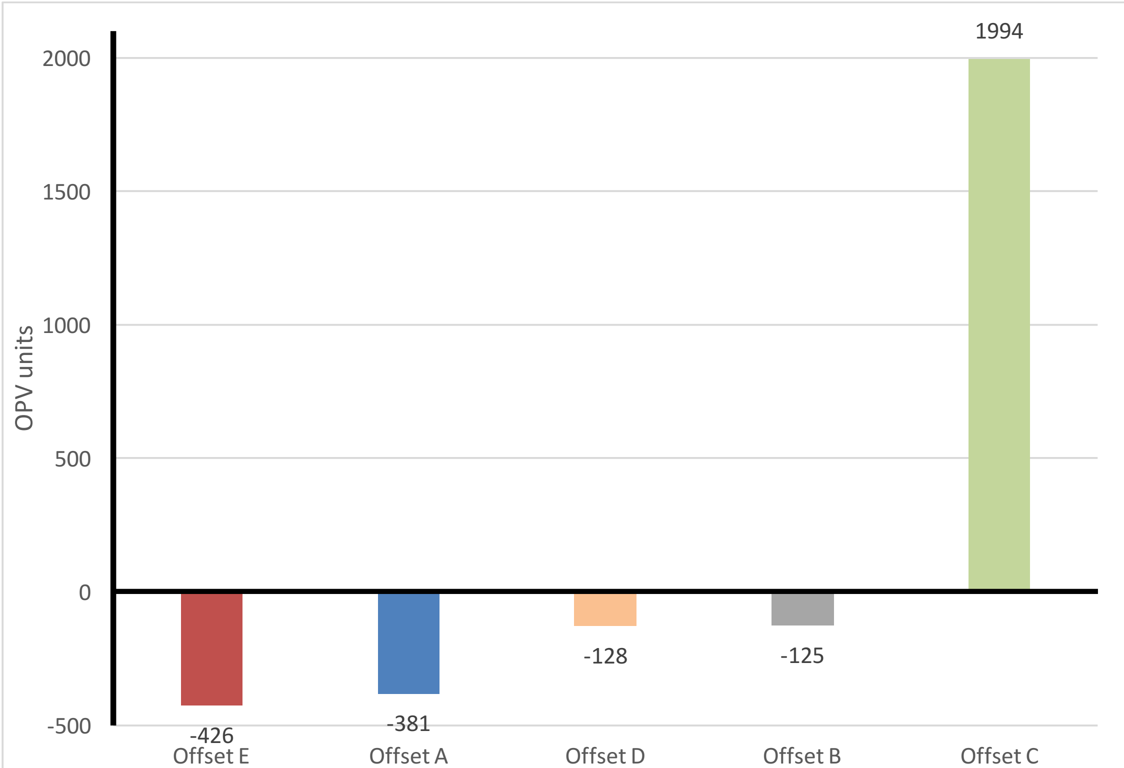

Figure 15 Offset Performance Value (OPV) results per offset area

Key:
Areas: Offset A = Chailhuagón sub-basin; Offset B = Alto Jadibamba sub-basin; Offset C = Toromacho sub-basin; Offset D = Alto Chirimayo sub-basin; and Offset E = Chugurmayo sub-basin

AMOEBA diagrams

AMOEBA diagrams were constructed for each potential offset area, in order to analyze the selected indicators independently and identify the key landscape aspects that could be strengthened/enhanced to improve the overall outcome (Figures 16 through 20). The AMOEBA diagram allows determining where flaws occur, distinguishing the issue areas, and drawing some conclusions about corrective actions (see Subsection 4.3.1.3).

The most significant under-performance of Offset A (Chailhuagón sub-basin), in relation to the impact and benchmark areas, occurs at the level of the Edge Density (ED) landscape indicator (Figure 16). This indicator is used as a proxy measure of the landscape function, assuming that it has a close relationship with the biotic interactions of the habitat addressed (see Table 16, Subsection 4.3.1.3); edges are often responsible for increased predation, invasion of exotic plant species, and in many cases act as barriers for animal movement (McGarigal, n.d.). In this regard, considering a hypothetical monitoring scenario, in the effort of improving the performance of Offset A, potential corrective measures should focus on minimizing the degree of the peatland patches' edge depth and contrast within the landscape in which this area is immerged (Chailhuagón sub-basin).

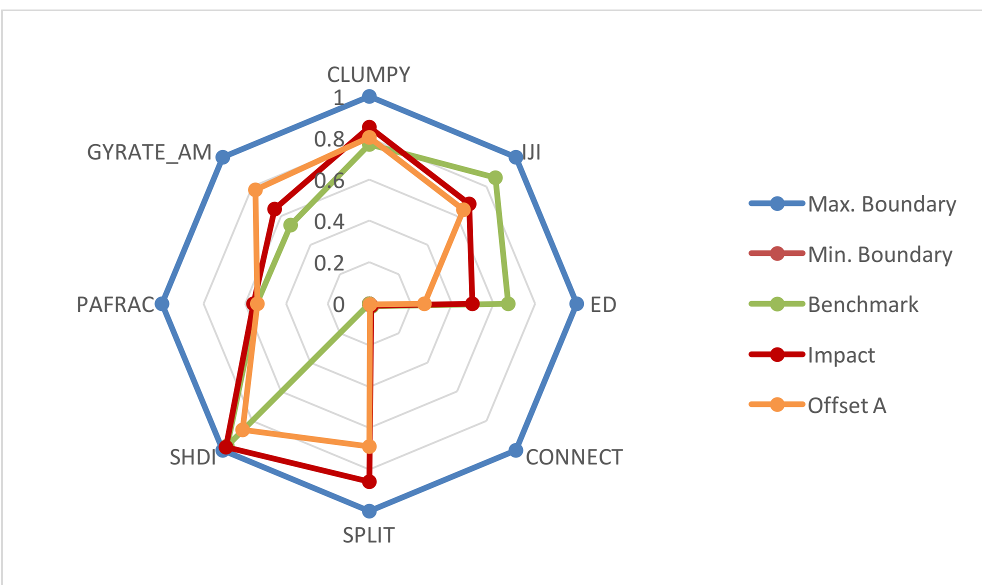

Figure 16 AMOEBA diagram - Offset A (Chailhuagón sub-basin) results*
(*) See Table 16 (Subsection 4.3.1.3) for description of indicators

Figure 17, on the other hand, suggests that the sub-basin in which Offset B is located (Alto Jadibamba) presents excellent connectivity characteristics (GYRATE_AM indicator), in comparison to the impact and benchmark areas' sub-basins, but behaves poorly in terms of its patch diversity level (SHDI indicator). Likewise, as in the precious case, Offset B presents a significant under-performance, in relation to the impact and benchmark areas, at the level of the ED landscape indicator. Considering a hypothetical monitoring scenario, in the effort of improving the performance of Offset B, potential corrective measures should focus, again, on minimizing the degree of the area's edge depth and contrast. Also, a better result can be achieved by increasing the number of patch types within the sub-basin where the Offset is located (Alto Jadibamba).

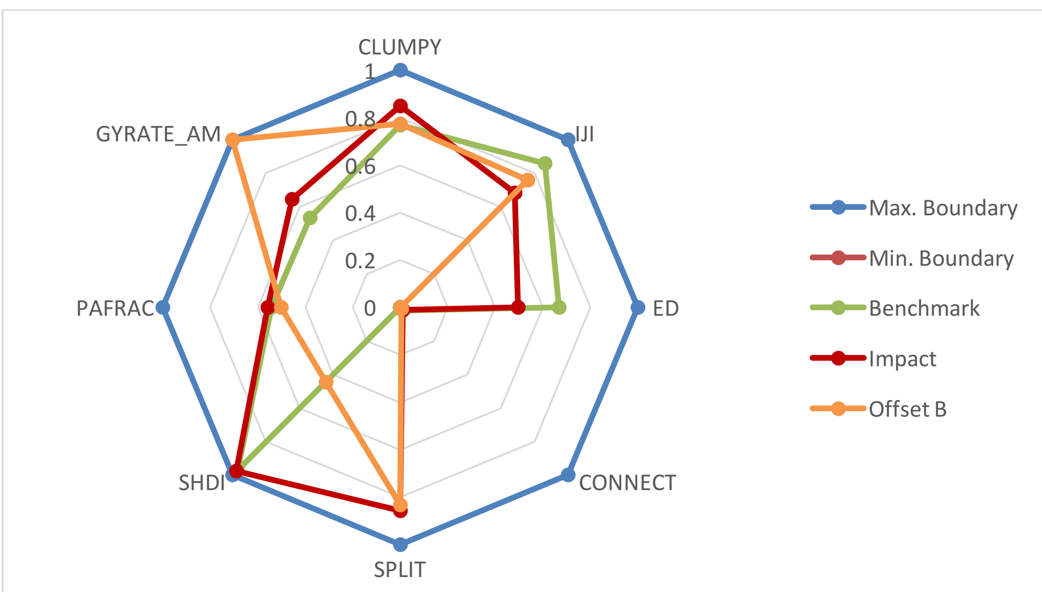

Figure 17 AMOEBA diagram - Offset B (Alto Jadibamba) results*
(*) See Table 16 (Subsection 4.3.1.3) for description of indicators

In the case of Offset C (Toromacho sub-basin), according to Figure 18, this area either over-performs in relation to the impact area, or presents a similar behavior, in almost all of the assessed indicators, being SPLIT and IJI the exceptions. These results suggest that the peatland patches within the landscape in which Offset C is immerged (Toromacho sub-basin), present a greater subdivision, and are more interspersed. Under a monitoring scenario, potential corrective measures could focus on improving the connectivity of the area's peatlands.

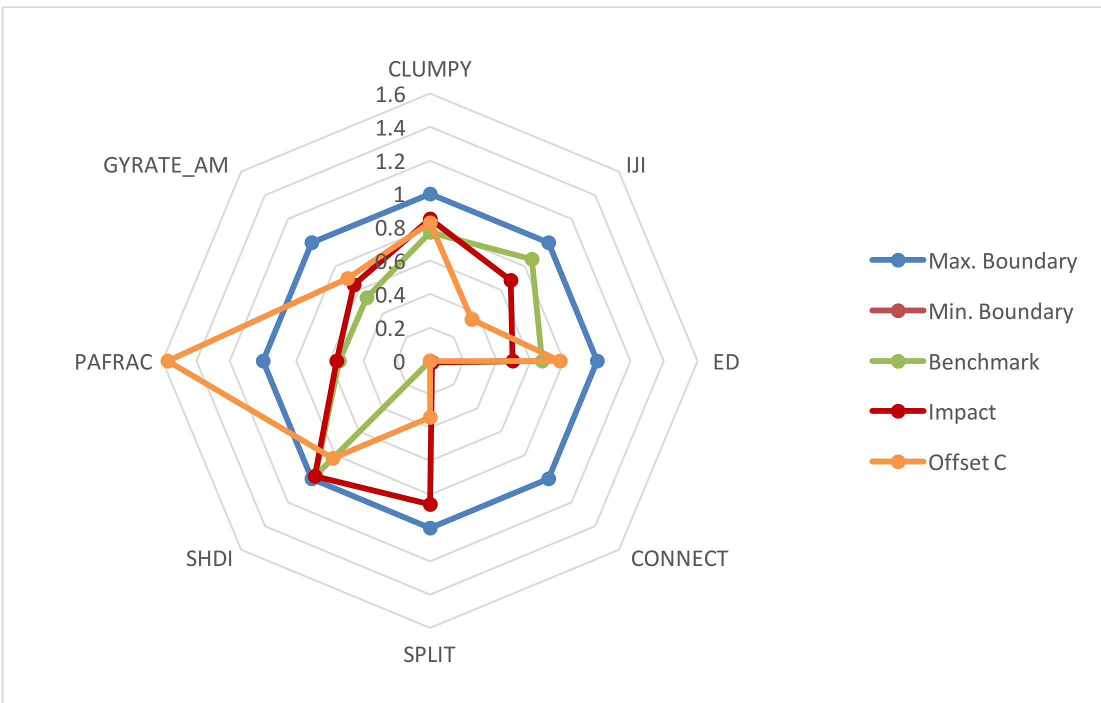

Figure 18 AMOEBA diagram - Offset C (Toromacho sub-basin) results*
(*) See Table 16 (Subsection 4.3.1.3) for description of indicators

Moving forward, as presented in Figure 19, Offset D (Alto Chirimayo sub-basin) presents an equivalent behavior to the impact and benchmark area in four of the assessed indicators, and a slightly poorer behavior in the remaining four: ED, IJI, SPLIT, and CLUMPY. In this case, potential management measures, under a hypothetical monitoring scenario, could focus on minimizing the degree of the peatland patches' edge depth and contrast within the landscape in which this area is immerged (Chirimayo sub-basin), as well as in improving the connectivity of the area's peatlands.

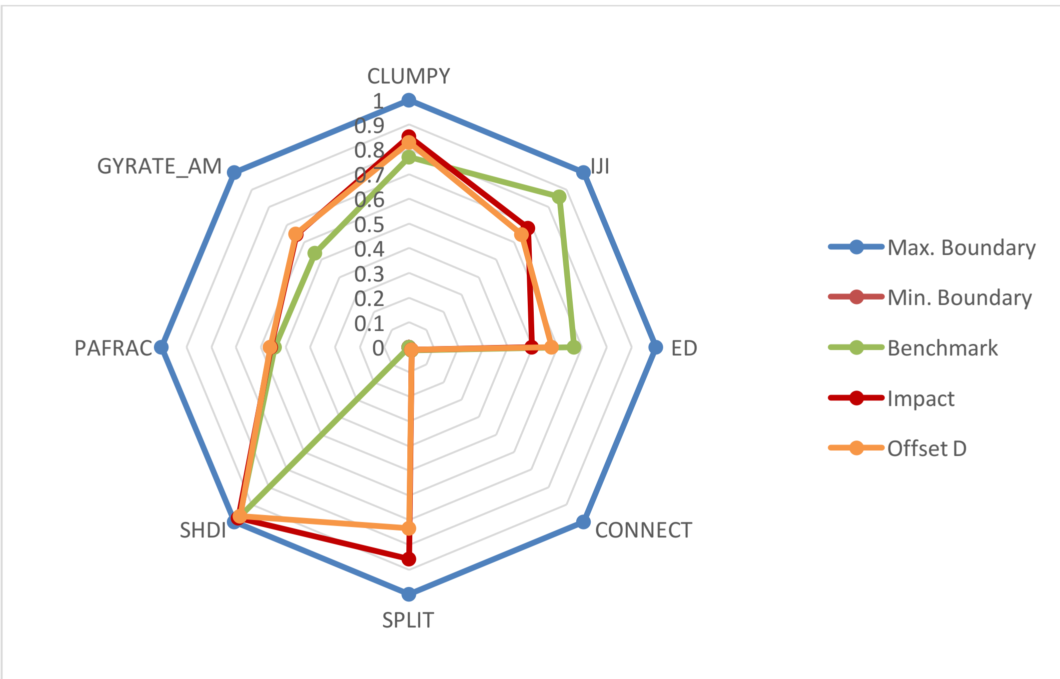

Figure 19 AMOEBA diagram - Offset D (Alto Chirimayo sub-basin) results*
(*) See Table 16 (Subsection 4.3.1.3) for description of indicators

Finally, in the case of Offset E (Chugurmayo sub-basin) (Figure 20), since this patch is located within the same sub-basin as the benchmark area (i.e., same landscape boundaries considered), the results of the class and landscape level indicators calculated are the same. In relation to the impact area, Offset E presents slightly poorer results for the CLUMPY, PAFRAC, and GYRATE_AM indicators.

These results suggest that the peatland patches within the landscape in which Offset D is immerged present a greater disaggregation, that such area has a poorer connectivity, and presents patches with more regular shapes, which can be correlated with the amount/impact of anthropogenic use of the landscape (Krummel, Gardner, Sugihara, O'Neill, & Coleman, 1987).

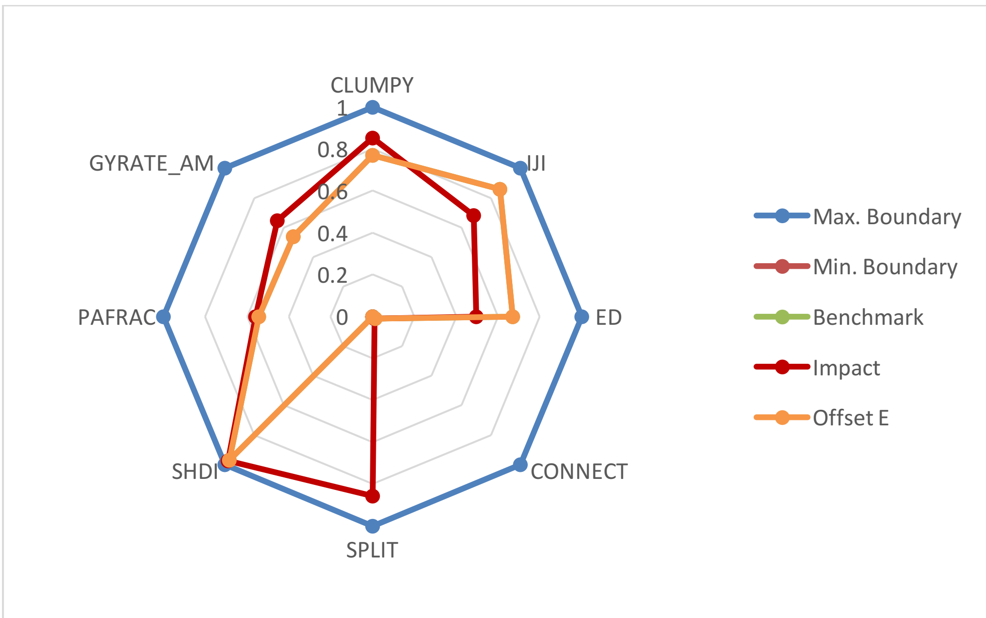

Figure 20 AMOEBA diagram – Offset E (Chugurmayo sub-basin) results*
(*) See Table 16 (Subsection 4.3.1.3) for description of indicators

4.4.2.3. Offset Performance Logic Model output

As a result or output, the OPLM determines (in this case) which portfolio of offset areas performs the best in terms of its ecological equivalence to the impact area, within a specific landscape context. Considering that Offset C (Toromacho sub-basin) is the only area yielding a positive OPV, and that each of the five potential offset portfolios contain at least two or more offset areas with negative OPVs, none of these is adequate enough to offset the corresponding impacts, from a landscape context perspective. Because of this, for this particular case, the identification and analysis of additional potential offset areas is required.

4.4.2.4. Offset Performance Logic Model outcome and impact

The OPLM's expected outcome is to achieve ecological equivalence between the offset and impact area in terms of the landscape context, while the expected impact or goal of the model is to achieve no net loss, or net gain, of biodiversity. Considering the first application (selection of the most appropriate offset site from a set of potential offset areas; i.e., analysis across space).

By determining that none of the identified potential portfolios of offset areas is adequate enough to offset the future impacts, and thus achieve a no net loss of biodiversity, the offset developer is required to identify additional potential offset areas and assess them using the OPLM process again.

Without the use of the OPLM, and thus without the consideration of a landscape context (using only the HH and BSI metrics), offset Portfolios 1 through 5 (see Table 39) would have been considered appropriate alternatives to offset the corresponding impacts. The impact and selected offset areas would not have been ecological equivalent in terms of their landscape location, ultimately resulting in a net loss of biodiversity.

4.5. Step 5: Integration of results into a decision making tool

4.5.1. Integration of the products obtained through Steps 1 to 4

The different products obtained through Steps 1 to 4 of my research can (and should) be used in conjunction for the implementation of successful biodiversity offset strategies in Latin America, as well as for their regulation and evaluation over time. In the effort of providing an integral and practical tool for stakeholders to use when working on such practices, the mentioned products were integrated into a structured stepwise decision making tool (Product P5, see Figure 1 and Table 11). This structure allows the user to explore key biodiversity offset issues (e.g., stakeholder engagement, accounting, monitoring) and discover the tools (e.g., menu of metrics, decision making tree) and methods (e.g., OPLM) that will help him or her to address them.

Considering the achievement of no net loss of biodiversity as the ultimate common goal, this tool can be used as: (1) a planning guideline for developing or refining biodiversity offset programs; (2) a common frame of reference for collaboration and sharing best practices and lessons learned; and/or (3) a tool to support the development of a monitoring program to evaluate the effectiveness of the strategy implemented, among others.

The tool (Product P5)[33] is presented in Appendix F. It comprises the following steps.

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[33] See Figure 1 and Table 12 for further descriptions of products.

- **Step 1:** Validation of criteria and attributes that offset metrics should comply with stakeholder engagement
- **Step 2:** Metric selection
- **Step 3:**
    - Application 1: Selection of best offset area alternative
    - Application 2: Monitoring the development of a specific established offset area

4.5.2. Potential for policy evaluation and design

Once stakeholders have developed confidence in the structure and behavior of the tool, it could be used to design and evaluate biodiversity offset policies for improvement. The interactions of different policies must also be considered, assuming that the impact of a combination of policies is usually not the sum of their impacts alone (Sterman, 2000).

Using Peru as an example (and the same BOCS as the one presented in Subsection 3.4.1), the country launched in December 2014, a framework for the implementation of biodiversity offsets (Ministerial Resolution N. 398-2014-MINAM) at a national level. According to this framework, a biodiversity offset plan is mandatory for investment projects with a detailed Environmental Impact Assessment ([EIA], project with significant negative impacts), and voluntary (and highly recommended) for all others. It indicates that offsets should be implemented for residual impacts only, that offset areas should be ecologically equivalent to the impact areas and consider the landscape context, and that the strategy should be sustainable across time. More specifically, it states that:

- Offset areas should be selected considering landscape indicators such as fragmentation and connectivity.
- The biodiversity offset plan should include an estimation of the value of the impacted site and offset area.
- Measureable expected results should be included in the plan, considering the ecosystem functionality.
- The plan should include a monitoring and result evaluation system, with established indicators.
- The plan will be supervised and evaluated by the corresponding agency, which may result in modifications of the plan for improvement.

What the Ministerial Resolution N. 398-2014-MINAM fails to do is provide the necessary guidelines/tools to achieve each of the mentioned criteria. How should the project developer estimate the value of the offset and impact areas? What indicators should be used? How should the areas be monitored? In this context, the mentioned regulations estipulate that the Ministry of the Environment will approve the following documents.

- Methodological guideline and metrics for the characterization and cualitative and cuantitative valuation of the negative environmental impacts, consieirng biodiversity and ecosystem functionality.
- Guideline for the design and implementation of biodiversity offsets, including metrcs to determine impact lossess and offset gains.

The decision making tool developed can perfectly complement what the mentioned guidelines aim to provide: a menu of the different metrics for the evaluation of the impact losses and offset gains, a recommendation of the 'best' metric for a specific project context, a model to evaluate the impact in terms of ecological systems, and a framework for evaluating offset performance over time.

The tool can also be used to complement or improve regulations at the local or regional level, specifically in regards to the location of the offset area. As part of their land use and zoning plans, local/regional governments can identify potential offset areas or zones for each ecosystem type within the corresponding locality. When using the tool to select the best offset area alternative across space (Application 1, see Subsection 3.3), the offset developer could use this set of potential areas as a first filter of the areas on which to run the OPLM. A good example is the *Mapeo de Formulas Equivalentes* (MAFE) tool of the Colombian Government, which looks for areas that area ecologically equivalent to the one being impacted. This software allows the identification of fragments of the same type of ecosystem as the impact one, with the same or better viability due to size and landscape context that could potentially be used as offset areas.

5. CHAPTER 5: CONCLUSIONS

5.1. Summary of conclusions

Most of current existing metrics do not comply with the criteria and attributes identified by Latin American stakeholders against which to evaluate the adequacy of offset metrics by Latin American stakeholders. Moreover, these present an overall poor behavior when assessed against indicator desirable properties (Munn, 1988; Noss, 1990) and attributes of suitable forms of metrics (BBOP, 2012). These results support the need for a more comprehensive tool for stakeholders to use when evaluating the success of biodiversity offsetting strategies in Latin America.

The Offset Performance Logic Model (OPLM) developed for evaluating the performance of offset sites over time and across space, in relation to their equivalence to the corresponding impact areas, overcomes the identified gaps and limitations of existing offset metrics. It allows stakeholders to develop interventions that can be adequately evaluated in the future, and assess the adequacy of offset areas in terms of their location within the landscape.

When using a biodiversity offset case study to determine offset requirements using current metrics, it was proven that these, on their own, are not adequate enough to determine equivalences, and that the OPLM acts a ‘second filter’ to identify offset areas that are equivalent to the impact area. The use of the OPLM in offsetting schemes contributes towards achieving ecological equivalence between impact and offset areas, and thus a no net loss of biodiversity.

Finally, by integrating the OPLM and the rest of products obtained through Steps 1 to 4 of my research into a stepwise decision making tool, I provide a structured process for determining the offset strategy' success in a systematic and adaptive way. This tool directly satisfies the objective of my research; it provides a practical and structured tool for assessing the ecological equivalence between biodiversity impact losses and offset gains in Latin America over time and across space. It contributes to the achievement of successful biodiversity offset strategies and acts as a platform to evaluate the success of these strategies over time. The tool has the potential of stimulating discussions both among offset developers and policy makers. In the first case, regarding the use of the best practices for the implementation of successful offsets, and in the second, regarding the development of regulations for the achievement of no net loss of biodiversity, looking to support businesses in achieving such a goal.

5.2. Limitations and recommendations

- **Validation/improvement of results with stakeholders**: The developed tool was disseminated among the stakeholders involved during Step 1 of my research and they were asked for feedback on the final product. This information will be collected, integrated, and used to validate and improve the tool. This should be done on a periodic basis, making sure to keep the tool updated according to new offset research and policies being pit into place.

- **Sensitivity test:** The Offset Performance Logic Model was tested using only one BOCS, located in Peru's highlands, targeting one specific type of ecosystem, specifically peatlands. However, it is important to test the tool across different types of ecosystems (e.g., forests and desserts) as a means of assessing its sensitivity under a series of different scenarios that present 'extreme' values for specific biotic (e.g., vegetation cover, species richness) and abiotic (e.g., temperature, elevation, precipitation) factors. 'Extreme' condition tests are critical tools to discover flaws in models and set the stage for improved understanding (Stedman, 2000).

  At the same time, according to the results presented in Subsection 4.4, the two metrics considered (Habitat Hectares [HH] and Biodiversity Significance Index [BSI]) have a similar behavior when accounting for losses and gains for the selected case study. This suggests that impact losses and offset gain calculations are not dependent on the type of metric being used. However, this might not necessarily be the case for other types of projects, especially for those that involve different types of impacts, and that are located in environments with different ecological characteristics. It is important to test the HH and BSI metrics, as well as the rest of the metrics considered in the analysis, under different project types, in order to be able to generalize the results obtained.

- **Definition of study area and boundaries**: Different offset areas within the same study site boundaries (e.g., same basin or sub-basin), would present equivalent values for the condition and landscape context indicators, as these consist of metrics that are calculated at the class and landscape levels, respectively. In this sense, the Ecological Dow Jones Index (EDJI) values for both criteria would be equivalent, and such areas will only differ in terms of their Core Area Index (CAI). In such cases, the final Offset Performance Value (OPV) would only depend on the area's CAI.

- **Landscape function indicators considered**: According to Noss (1990), these should include variables such as: nutrient cycling rates, energy flow rates, disturbance processes, colonization rates, biomass and resource productivity, among others. However, given the complexity of such indicators in terms of the time and data requirements involved, Edge Density (ED) and Perimeter-Area Fractal Dimension (PAFRAC) were chosen as proxy measures for function. It is assumed that these have a close relationship with the biotic interactions of the habitat addressed, in the first case, and with the environmental regimes and processes of the landscape, in the second (Appendix D).

- **Impact due to project development, and counterfactual scenario, might not be equivalent**: When selecting the best performing offset area, the OPLM assumes that the impact that will be generated by the project development, is equivalent to the impact that could be generated under the counterfactual scenario. However, the conversion of a given area of a specific ecosystem to, for example, mining, is not necessary equivalent to the conversion of a given area of the same ecosystem to, for example, smallholder agriculture, as it may retain significant biodiversity values. The use of multipliers can help to overcome this issue. As stated in Subsection 4.3.1.3, in order to be confident of achieving no net loss, multipliers are recommended to increase the amount of biodiversity gains required – in this case, the offset core area.

- **Consideration of 'special values':** The OPLM, itself, does not take into account the presence of 'special values' on the impact area. These include threatened/rare species, unique or threatened ecosystems/habitats, relevant ecosystem services, significant concentrations of migratory species, local cultural values, among others. A multiplier should be selected to assure a no net loss of the mentioned features. Which multiplier to select ultimately depends on the project's reality, objectives, and impact magnitude.

- **Consideration of ecosystem services**: The OPLM does not consider ecosystem services when assessing the balance between impact losses and offset gains. These should be incorporated either before the use of this model (e.g., included in the metric used to determine equivalences), or after, through the use of multipliers.

The value of ecosystem services could be incorporated by using the Global Footprint Network's Footprint Account Program (Borucke et al., 2013). This program provides an accounting framework to assess the ecological supply and demand of key ecosystem services by a means of two measures: biocapacity and ecological footprint. Biocapacity refers to the "amount of biologically productive land and sea area available to provide the ecosystem services" consumed, while ecological footprint is defined as "a measure of the demand populations and activities place in a given year, given the prevailing technology and resource management of that year" (Borucke et al., 2013, p. 519). Both values are expressed in mutually exclusive units of area necessary to a provide such environmental services. The ecological footprint should include all human demands that compete for space, and biocapacity all areas that provide such services. However, only those human demands, and areas that provide such services, for which consistent data sets exist, should be considered (Borucke et al., 2013).

- **Leakage[34] assessment:** The OPLM does not consider the displacement of the impact that would have happened in the offset area under the counterfactual scenario. According to BBOP's Standards on Biodiversity Offsets, an assessment should be undertaken to identify potential leakage resulting from the offset activities, and the offset strategy should include measures for addressing such a risk, which should be put into effect during implementation (BBOP, 2012). Virah-Sawmy, Ebeling, and Taplin (2014), for example, present an equation to calculate the net impact on biodiversity that

[34] "The displacement by the offset of activities that harm biodiversity from one location to another" (BBOP, 2012).

includes a leakage factor. When calculated, it can be used as a discount factor of the gains provided by the offset site.

- **Integration with other biodiversity offset tools and frameworks**: Although the developed decision tool represents a practical and structured tool for assessing the ecological equivalence between biodiversity impact losses and offset gains over time and across space in Latin America, it does not constitute a stand-alone strategy for the implementation of successful offsets. It should be used in conjunction with a set of specific regulations, policies and frameworks in order to achieve successful outcomes, as well as specific considerations on a case by case basis (e.g., presence of sensitive species, threatened ecosystems, etc.).

5.3. Final Comments

Compared to other instruments for biodiversity conservation and environmental sustainable development, most biodiversity offset schemes are still relatively incipient in Latin America with regards to their implementation and proven success; so there is still a significant amount to be researched and learned (The Organization for Economic Cooperation and Development, 2014). Nevertheless, without an appropriate offset-impact equivalence evaluation procedure in place, tailored to the context, needs, and reality of Latin America, the implementation of biodiversity offsets has been (and currently is) proliferating at a surprisingly accelerated pace in the region.

The potential risks that this situation entails are of much concern; unless an appropriate compensation is ensured, it is unlikely that biodiversity offsets will achieve the goal of no net loss of biodiversity. Moreover, if offset gains do not achieve equivalence to what is lost, they may cause more harm than good and result in an even greater loss of biodiversity. “If done right, offsets can play a useful role in conservation, but if done wrong, they can undermine conservation efforts” (Brunner, 2015).

In this context, my research plays a key role for mitigating the mentioned risks, contributing to the achievement of successful biodiversity offset strategies by providing a decision making tool to better assess the equivalence between offset gains and project impacts and to systematically determine the success of these strategies over time. My research will significantly contribute towards achieving the different potential benefits for industries, governments, and regulation entities that biodiversity offset strategies offer, as well as for conservation institutions (i.e., NGOs).

Benefits for industries include adhering to the mitigation pyramid framework with successful results regarding biodiversity conservation in the case of residual impacts. At the same time, offsets provide government regulators and policy makers the opportunity to ensure that every residual impact on biodiversity is being adequately managed by the corresponding industry. Furthermore, offsets can also be a mechanism to ensure that regional conservation goals are integrated into governmental and business planning (Saenz et al., 2013). The development of a consistent decision making tool to help determine the success of biodiversity offsetting strategies throughout Latin America, as part of my research, has the potential to benefit each of the stated entities, helping them achieve the mentioned outcomes.

APPENDICES

APPENDIX A: Matrix 1 - Comparison of core principles of the selected metrics for assessing biodiversity values

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
1. Habitat Hectares (HH)	Native Vegetation Management Framework	Victorian Department of Natural Resources and Environment (NRE) - - State of Victoria, Australia.	Offsetting native grassland clearances in Victoria, Australia	Area x Quality Quality = condition + landscape context	$Area_{impact}$ x $score_{impact}$ ≤ $Area_{offset}$ x $score_{offset}$	- Uses a set of indicators that describe site condition and its landscape context (nature of landscape surrounding the site). - Indicators are weighted and combined into a habitat score. - Indicators include: • Seven Site Condition indicators, assessed on the field, considered important for a wide range of species and able to be rapidly assessed by non-experts: number of large trees present, tree cover, understory components, lack of weeds, recruitment, organic litter, logs. • Three Landscape Context indicators, generally assessed off-site using GIS: patch size, neighborhood, distance to core area. - The attributes selected for assessing Site Condition will vary with context and vegetation type. - Vegetation quality is defined as: the degree to which the current vegetation differs from a benchmark.

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
1	Native vegetation communities (Ecological Vegetation Classes)	Community - ecosystem	Ecological communities	Pre-defined (although some indicators may or may not be considered depending on the vegetation type being assessed)	Several	X E.g.: large trees, understory components	X E.g.: canopy cover, weed cover, organic litter	X Recruitment	Yes	Yes	Parkes, Newell, & Cheal, 2003

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
2. Units of Global Distribution (UD)	Rio Tinto's conservation strategy	Rio Tinto QMM (Quit Madagascar Minerals operation)	Company's voluntary offsetting schemes - to approach the question of conservation significance when offsetting	% of individuals affected of Species X or (in case of unavailable data) % of habitat loss of Species X	% individuals affected of Species X $_{impact}$ ≤ % individuals propagated/breed of Species X $_{offset}$ or (in case of unavailable data) % of habitat loss of Species X $_{impact}$ ≤ % of habitat gain of Species X $_{offset}$	- 1UD = 1% of global population of species X (# of mature individuals) or (in case of unavailable data) - 1UD = 1% of global distribution of species X (in ha) - Only for high priority species: local endemics, CR or EN (IUCN).

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
2	High priority species / species of concern	Population - species	Species	Pre-defined	Single	X	-	-	No	No	Temple et al., 2012

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
3. Uniform Mitigation Assessment Method (UMAM)	-	Department of Environmental Protection - Florida, USA	Determine the amount of mitigation needed to offset adverse impacts to wetlands and other surface water systems and to award and deduct mitigation bank credits.	Area x Quality Quality = condition + landscape context + habitat functionality	$\Delta[(LL + WE + CS)/30]_{impact} \times Area_{impact}$ $\leq$ $\Delta[(LL + WE + CS)/30]_{offset} \times Area_{offset} \times PF$ LL = Location and landscape support WE = water environment CS = community structure PF = preservation adjustment factor	- Provides a standardized procedure for assessing the ecological functions provided by wetlands and other surface water systems, the amount that those functions are reduced by a proposed impact, and the amount of mitigation necessary to offset that loss. - Involves quantitative and qualitative analysis: • Qualitative: characterizes assessment areas and their function. • Quantitative: provides indicators, which are scored based on the qualitative analysis, for determining gains and losses. Indicators include: location and landscape support, water environment and community structure. Requires only a visual assessment, or at least a qualitative one (no numerical data required).

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
3	Ecosystem services / wetland functions	Community - ecosystem	Ecological communities	Pre-defined	Several	X E.g.: proportion of exotic species	X E.g.: presence of topographic features	X E.g.: habitat provision	No	Yes - to some extent (based on visual qualitative assessment)	Florida Department of State, n.d.

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
4. Biodiversity Significance Index (BSI)	Biodiversity Benefits Index (BBI)- NSW Environmental Services Scheme (ESS)	New South Wales Department of Natural Resources – State of New South Wales, Australia	- The BBI metric was developed to score benefits of changes in land use or management by the landowners relative to a range of environmental services. - Specifically, the BSI component of this metric is used to determine the current value or biodiversity significance of the site that will be subject to land use change.	Area x Quality (biodiversity significance score)	$area_{impact}$ x BSS_{impact} ≤ $area_{offset}$ x BSS_{offset} BSS = VC(LC+CS)/200 BSS = Biodiversity Significance Score VC = vegetation condition CS = conservation significance LC = landscape context	- Based on the HH approach, modified according to current and proposed land uses applicable to the NSW ESS. - The biodiversity significance score takes into account the following components: • Vegetation condition - VC (a set of 8 indicators) • Conservation significance - CS (indicator of the amount of vegetation type in the landscape compared to a time prior to agricultural development) • Landscape context - LC (regional, local and site context indicators).

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
4	Native vegetation communities at a catchment or regional scale	Community - ecosystem	Ecological communities	Pre-defined	Several	X	X	X Recruitment	Yes	Yes	Oliver & Parkes, 2003

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
5. Conservation Significance Index (CSI)	Biodiversity net impact (BNI)	Virah-Sawmy, Ebeling, & Taplin (2014). Mining and biodiversity offsets: A transparent and science-based approach to measure “no-net-loss”.	-The methodology was created to help design biodiversity offsets to realize their potential in enabling more responsible mining that better balances economic development opportunities for mining and biodiversity conservation. - By using the CSI, the irreplaceability and vulnerability of species impacted is evaluated.	Area x %CSI %CSI = # of sensitive species / available habitat x 100	$Area_{offset}$ x $\%CSI_{offset}$ x [counterfactual scenario x conversion factor x %effectiveness x (1 - % leakage)]$_{offset}$ = $Area_{impact}$ x CSI_{impact} x [counterfactual scenario x (1 - % leakage)]$_{impact}$	Considers the following factors: • % Effectiveness: precautionary approach, assuming a sub-optimal success - based on previous similar projects and/or expert criteria, and depending on implementation, complexity and degrees of risk that are deemed necessary. • % Leakage: risk of displacing, rather than avoiding biodiversity losses in counterfactual scenario. Methodologies have been approved for biodiversity impact assessment under the Climate, Community and Biodiversity Standards. • Counterfactual scenario: depends on the biodiversity target and the reality of the assessment area. E.g., deforestation rates, pouching rates, etc. • Conversion factor: the conversion of one hectare of forest to mining use does not necessarily translate into the same biodiversity loss as the loss of one hectare under the counterfactual scenario for the impacted or offset site. A conversion factor needs to be determined depending on the counterfactual scenario and biodiversity target.

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
5	High priority species / species of concern	Population - species	Species	Pre-defined - although the approach for determining the value of each factor is case dependent	Several	X	-	-	No	No	Virah-Sawmy, Ebeling, & Taplin, 2014

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
6. Offset ratio - US Wetland Banking	US Wetland Banking / compensatory mitigation	US Federal Government - Clean Water Act (1972)	Driven by compliance to the Clean Water Act (S404) and the principle of no net loss, for applicants filing for permits to drain, fill, or dredge a wetland (or stream). The policy objective is to offset unavoidable adverse impacts to wetlands through compensatory mitigation that replaces wetland functions and values.	(Area being lost) x (mitigation ratio)	- Depends on local and state authorities. - Most of the times, a simple index is used, such as wetland area.	- Developers can fulfil their compensatory mitigation obligations themselves, or they can pay third parties to do this. Options include: (1) buy wetland credits from mitigation banks; (2) pay fees (‘in-lieu-fees’); or (3) pay third parties. - In theory, for every hectare of wetland destroyed, a hectare of comparable wetland must be restored or recreated within the defined service area (watershed). - The amount of required compensation must be sufficient to replace lost wetlands acreage and aquatic resource functions. - The final appropriate ratio is determined by district engineers on a case-by-case basis, based on the following factors: • Compensation method (e.g., restoration, establishment, enhancement, preservation) • Likelihood of success • Differences between the functions lost at the impact site and the functions expected to be produced by the compensation • Temporal losses of aquatic resource functions • Difficulty of restoring or establishing the desired aquatic resources and functions • Distance between the affected aquatic resource and the compensation site.

Metric name	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
6	Wetland habitat	Community - ecosystem	Ecological community	The mitigation ratio is supposed to be case-dependent	Single	X	-	-	No	No	Department of the Army, Corps of Engineers, and Environmental Protection Agency, 2008.

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
7. Offset ratio - US Conservation Banking	US Conservation Banking	US Federal Government, Fish and Wildlife Service - Endangered Species Act	Compensate impacts on endangered or threatened species under the Endangered Species Act in order to obtain a no net loss of biodiversity.	Context specific: at least 1 to 1 ratio for area supporting nest site or family group.	In its simplest form: 1 credit = 1 acre of habitat or the area supporting one nest site or family group.	- Focus on species - Credit unit: individuals, breeding pairs, acres, family groups, etc. - The method for calculating bank credits should be the same as the one used for calculating project impacts: affected acres, affected species, affected family groups, etc. - Methods of determining available credits may rely on ranking or weighting of habitats based on habitat condition and/or function, size of the parcel, or other factors. It depends on species conservation strategy.

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
7	Species	Population - species	Species	Case-dependent	Usually single	X	-	-	No	No	US Fish and Wildlife Service, 2003

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
8. Adaptation of Habitat Hectares (DEFRA metric)	Metric for Biodiversity offsetting pilots in England, UK	Natural England - executive non-departmental public body, sponsored by the Department for Environment, Food and Rural Affairs (DEFRA, 2011).	- Have a suitable metric to quantify impacts on biodiversity and ensure that those impacts are properly assessed and that offsets lead to genuine environmental gain. - The metric is being used in six offsetting pilot areas in England, since 2012.	Area x condition x distinctiveness	$(\text{Condition x distinctiveness x area})_{\text{impact}}$ = $(\text{Condition x distinctiveness x area})_{\text{offset /}}$ multipliers Multipliers = risk, time and location	- Variation of the HH approach. - The value of habitats is determined on the basis of 3 criteria: • Distinctiveness: reflects the rarity of the habitat and the degree to which it supports species rarely found in other habitats. Assessed as low, medium or high. • Condition: calculated using the Higher Level Agri-environment Scheme tool. Assessed as good, moderate or poor. This tool assesses habitat condition depending on the type of habitat. Each habitat type has different condition assessment criteria. These criteria includes parameters such as: species richness, cover, presence of specific habitat structures, anthropologic and natural degradation level, ecological succession, adjacent land uses/types, tree's health condition, etc. • Area of habitat in hectares. - Offset actions should occur in habitats of higher distinctiveness than the one where the development is occurring. - Multipliers included, depending on offset risk, time and location.

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
8	Habitat	Community - ecosystem	Ecological community	Pre-defined	Several	X (for most habitat types)	X (only for some habitat types)	X (only for a few habitat types)	No	No	DEFRA, 2012

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
9. Module Assessment method (MAM)	-	Switzerland Federal Office for the Environment (FOEN)	Compliance with the Federal Law for the Protection of Nature and Landscape in Switzerland. This law mandates "replacement" of protected biotopes where impacts are unavoidable.	Area x quality factors	$Area_{offset} \times QF_{offset} = Area_{impact} \times QF_{impact}$	- To define the ecological value before the impact, the study area is divided into sectors. The area of each sector is recorded. - The value of each sector, both in the impact and offset areas is determined based on variables to which quality factors are allocated: • Variables for impact area: ○ Age of sector ○ Presence of surrounding habitats ○ Importance of network function ○ Natural dynamic ○ Maturity degree ○ Species richness ○ Presence of demanding species. • Variables for offset area: ○ Time for offset to deliver function ○ Presence of surrounding habitats ○ Importance of network function ○ Natural dynamic ○ Need for maintenance activities ○ Regional representatively.

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
9	Habitat	Community - ecosystem	Ecological community	Pre-defined	Several	X	X	-	No	No	Morandeau & Vilaysack, 2012

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
10. Biotope Valuation (BV)	*Ausgleich* procedure - compensation measures	Impact Mitigation regulation – *Eingriffsregelung:* instrument, which entered into force as part of the German Federal Nature Conservation Act.	Landscape conservation instrument to address mitigation and compensation for impacts from developments and projects, following a mitigation hierarchy	Area x ecological value	$\{[(C1 + C2 + C3 + C4) \times (C5 + C6 + C7 + C8)]/576*100\} \times area_{offset} = \{[(C1 + C2 + C3 + C4) \times (C5 + C6 + C7 + C8)]/576*100\} \times area_{impact}$	- The method consists in building lists of biotopes types (types of land use) at the local level and ascribing score values to them (most often for 1m2) - Every biotope is assessed against the following eight ecological criteria: • Internal features of biotopes (each criteria is scored from 1-6): ○ C1. maturity of the biotope ○ C2. unaffected state of the biotope ○ C3. diversity of the layer structure ○ C4. diversity of species • External features of biotopes (each criteria is scores from 1-6): ○ C5.rarity of biotopes ○ C6.rarity of the biotope species ○ C7. sensitivity of biotopes ○ C8. threat to the number and quality of biotopes - Values depend on the biotope's degree of ‘naturaty’ and rarity, its threats and capacity to be restored. The points are allocated based on the interdisciplinary expert valuation.

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
10	Habitat	Community - ecosystem	Ecological community	Yes (although biotope values vary per state / location)	Several	X	X (Indirectly)	-	No	No	Morandeau & Vilaysack, 2012

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
11. Habitat Units (HU)	Habitat Evaluation Procedures	Fish and Wildlife Service Federal Agency, US	Developed in response to numerous legal mandates in the United States requiring that impact assessments should quantify the extent and status of natural resource components, their susceptibility to loss, and the implications of development alternatives and mitigation measures on those components.	Area x quality quality = suitability index	HU = HSIs x Area HSIs = value of area / value of benchmark HSIs = Habitat Suitability Indices (0-1)	- Addresses habitat availability and carrying capacity for selected evaluation species. - It is based on the assumption that certain habitat variables can be measured (e.g., vegetation height) which are strongly correlated with the ability of an area to support a given species. - Measurements of these variables are used to derive numerical habitat suitability indices (HSIs) which range from 0.0 to 1.0 and can be multiplied by the area of available habitat to obtain Habitat Units (HUs). - The method depends strongly on the ability of the practitioner to assign an accurate HSI and to identify clear relationships between carrying capacity and specific environmental variables.

<table>
<tr><th rowspan="3">Metric</th><th colspan="3">Offsetting target</th><th colspan="5">Use of indicators</th><th rowspan="3">Benchmark</th><th rowspan="3">Landscape context</th><th rowspan="3">Main Reference</th></tr>
<tr><th rowspan="2">Target</th><th colspan="2">Level of organization</th><th rowspan="2">Pre-defined? Or case-dependent?</th><th rowspan="2">Amount</th><th colspan="3">Attributes of biodiversity (Noss, 1990)</th></tr>
<tr><th>Noss, 1990</th><th>TNC, 2003</th><th>Composition</th><th>Structure</th><th>Function</th></tr>
<tr><td>11</td><td>Individual species</td><td>Population - species</td><td>Species</td><td>Case-dependent</td><td>Several or single (depends)</td><td colspan="3">Depends</td><td>Yes</td><td>No</td><td>US Fish and Wildlife Service (1980)</td></tr>
</table>

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
12. Significant Environmental Benefit (SEB) For the clearance associated with the mining and petroleum industry.-	-	Department of Water, Land and Biodiversity Conservation – State of South Australia, Australia.	Guide project developers involved with activities under the Mining Act 1971 and Petroleum Act 2000 (mining, petroleum, geothermal and exploration activities) with respect to the clearance of native vegetation under the Native Vegetation Act of 1991	Area x ratio	Offset area = Impact area x ratio	- The offset area is determined by the area and the relative quality of the vegetation proposed to be cleared, ranging from an offset of two times the cleared area (2:1) for clearance of poor quality native vegetation, to an offset of ten times the area cleared (10:1) for clearance of intact native vegetation. - The initial SEB ratio is determined by assessing the impact of the project or activity on the condition of the vegetation to be cleared. Variables considered include: alteration level of vegetation structure, scope for regeneration, level of disturbance, weed domination, clearing %, grazing evidence, litter cover. - If ecological restoration activities will be achieved on-site on completion of mining and/or petroleum activities, then the initial SEB ratio will be reduced by 50%. - If the project is impacting one of five key criteria established in the Native Vegetation Act, additional measures need to be ensured and the SEB ratio will be reduced by a further 50%.

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
12	Native vegetation	Community - ecosystem	Ecological communities	Pre-defined	Several (ratio depends on several indicators)	X	X	-	No	No	Department of Water, Land and Biodiversity Conservation, 2005

Metric name	Framework / methodology the metric is part of	Developed by / established through	Creation objective	Formula basics	Formula	General description
13. Offset ratios	-	Department of Environmental Affairs and Development Planning (DEADP) – Province of the Western Cape, South Africa.	Ensure that residual impacts on biodiversity and ecosystem services that are of moderate to high significance are compensated by developers in such a way that ecological integrity is maintained and development is sustainable	Area x ratio	offset area = impact area x offset ratio	- Use of a basic offset ratio linked to the conservation status of the affected ecosystem. - Ecosystems are classifies as: Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Least Concern (LT), according to their conservation status in terms of the National Spatial Biodiversity Assessment. - Offsets are calculated by multiplying the area lost by the offset ratio which has been pre-assigned to the affected ecosystem. - This ratio is then adjusted according to a number of biodiversity and ecosystem services considerations: ○ The condition of the affected habitat ○ The presence of threatened species ○ The presence of special habitats ○ The biodiversity process value of the affected habitat ○ The importance of biodiversity underpinning valued ecosystem services.

Metric	Offsetting target			Use of indicators					Benchmark	Landscape context	Main Reference
	Target	Level of organization		Pre-defined? Or case-dependent?	Amount	Attributes of biodiversity (Noss, 1990)					
		Noss, 1990	TNC, 2003			Composition	Structure	Function			
13	Ecosystem	Community - ecosystem	Ecological communities	Pre-defined (offset ratio depends on characteristics f affected ecosystems)	Single (although offset ratio depends on characteristics of the affected ecosystem)	X	-	-	No	No	DEADP, 2007

APPENDIX B: Matrix 2 - Characterization of biodiversity offset metrics according to indicator desirable properties (Munn, 1988; Noss, 1990), attributes of suitable forms of metrics (BBOP, 2012) and stakeholder criteria

Metric	"Indicator desirable properties" (Noss, 1990; Munn, 1988)											
	11. Geographic applicability (Latin America context)		**2. Sensitivity**		**3. Capability of providing continuous assessment over a wide range of stresses**		**4. Cost and time effectiveness and practicality**		**5. Ability to differentiate between natural and anthropogenic-induced cycles or trends**		**6. Relevancy to ecologically significant phenomena**	
	S	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**
HH	3	- Indicators designed based on Australian ecosystems and vegetation types - Problems regarding treeless vegetation types	3	- The presence of large trees and tree cover can be considered sensitive, but not to all impacts. - Individual values are turned into one single final value- reduces sensitivity. - It does not consider specific sensitive species.	4	Some stresses will only affect wildlife (e.g.: noise)	2	- Requires trained operators. - Having one final value makes it practical for practitioners.	3	- Individual values are turned into one single final value - it is not possible to identify the cause or source of the stress	4	Includes landscape variables, relevant to ecologically significant phenomena
UD	3	Can be applied anywhere, except in areas with no high sensitivity species or where there is no residual impact on high sensitivity species	4	Based on the abundance of high sensitivity species	2	if the stress is not affecting the species habitat, there will be no change on the indicator	3	When there is also no information on species global distribution, this needs to be estimated (area of occupancy), which can be complicated or inaccurate	1	Does not identify the source of the stress, only the result	2	If the phenomena is not affecting the species or its habitat, there will be no change on the indicator

Metric	"Indicator desirable properties" (Noss, 1990; Munn, 1988)											
	1. Geographic applicability (Latin America context)		**2. Sensitivity**		**3. Capability of providing continuous assessment over a wide range of stresses**		**4. Cost and time effectiveness and practicality**		**5. Ability to differentiate between natural and anthropogenic-induced cycles or trends**		**6. Relevancy to ecologically significant phenomena**	
	S	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**
UMAM	2	- Indicators designed based on Florida's wetlands	2	- It does not consider specific sensitive species. - Does not involve the numerical calculation of specific indicators - values are obtained through qualitative analysis	2	- Some stresses can't be identified by only qualitatively assessments. - Some stresses will only affect wildlife (e.g.: noise)	4	Relatively simple	2	- Does not identify the source of the stress, only the visual result. - Individual values are turned into one single final value	3	Some ecologically significant phenomena can't be identified by only visual, qualitatively assessments.
BSI	3	- Based on land uses applicable to New South Wales - Problems regarding treeless vegetation types	4	- The presence of large trees and tree cover can be considered sensitive, but not to all impacts. - Individual values are turned into one single final value- reduces sensitivity. - It considers sensitive species.	4	- Some stresses will only affect wildlife (e.g.: noise)	2	- Requires trained operators. - Having one final value makes it practical for practitioners.	3	- Individual values are turned into one single final value - it is not possible to identify the cause or source of the stress	4	Includes landscape variables, relevant to ecologically significant phenomena

Metric	"Indicator desirable properties" (Noss, 1990; Munn, 1988)											
	1. Geographic applicability (Latin America context)		**2. Sensitivity**		**3. Capability of providing continuous assessment over a wide range of stresses**		**4. Cost and time effectiveness and practicality**		**5. Ability to differentiate between natural and anthropogenic-induced cycles or trends**		**6. Relevancy to ecologically significant phenomena**	
	S	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**
CSI	4	- The considered factors can be applied anywhere, as there is no established methodology for their determination. - The CSI cannot be applied in areas with no high sensitivity species or where there is no residual impact on high sensitivity species.	3	- Considers the abundance of high sensitivity species - Indicators are collapsed into one final value	3	- If the stress is not affecting the species habitat, there will be no change on the CSI indicator. - However, the counterfactual scenario, conversion factor and %leakage factors can respond to a wide range of stresses	1	- There is no stablished methodology for determining each of the considered factors	3	- Considers counterfactual scenario, conversion factor and %leakage factors (its determination can point to the source of the stress).	2	- If the phenomena is not affecting the species or its habitat, there will be no change on the CSI indicator
US Wetland Banking	5		1		3	- Some stresses will only affect wildlife (e.g.: noise)	5		1		2	
US Conservation Banking	5		3	- Depends, whether it focuses on acreage or individuals.	3	- Depends, whether it focuses on acreage or individuals.	3	- Depends, whether it focuses on acreage or individuals.	1		2	- Depends, whether it focuses on acreage or individuals.

Metric	"Indicator desirable properties" (Noss, 1990; Munn, 1988)											
	1. Geographic applicability (LA context)		2. Sensitivity		3. Capability of providing continuous assessment over a wide range of stresses		4. Cost and time effectiveness and practicality.		5. Ability to differentiate between natural and anthropogenic-induced cycles or trends		6. Relevancy to ecologically significant phenomena	
	S	Notes	S	Notes	S	Notes	S	Notes	S	Notes	S	Notes
DEFRA metric	2	- Based in UK's ecosystem types (distinctiveness specifically)	2	- Distinctiveness does not vary - Condition is based on qualitative information	3	- Distinctiveness does not vary - Condition is based on qualitative information	5	- Relatively simple, as distinctiveness and condition values are pre-established	2		3	
MAM	2	- Based on Switzerland's biotopes	2	- Quality factors are not sensitive	2	- Quality factors are not sensitive	5	- Relatively simple	1		2	
BV	3	- Based on Germany's biotopes, but can be extrapolated to other realities	2	- Ecological value is determined qualitatively, using factors not that sensitive.	2	- Quality factors are not sensitive	4	- Relatively simple	1		2	
HU	5	- Indicators are case-dependent	3	- Depends on the selected indicators	3	- Depends on the selected indicators	1	- No. Users need to determine what indicators to use	3	- Depends on the selected indicators	2	- Depends on the selected indicators
SEB	3	- Only for tree ecosystems - but can be applied anywhere	2	Indicators, which are qualitative, are collapsed into one final value (ratio)	2		5	- Relatively simple	1		2	
Offset ratios	1	- The offset ratio is linked to the conservation status of affected ecosystem	1	- Depends on conservation status of ecosystems, which is already pre-assigned	1	- Does not change according to stresses	5	- Relatively simple	1		2	- Considers presence of sensitive species

Metric	BBOP attributes of suitable forms of metrics (2012)												TS1
	1. Capture type, amount, and condition or quality of the biodiversity that is being lost or gained		2. Quantify the losses and gains at the species, communities, habitats, and ecosystem levels within project's context		3. Enable the calculation of residual losses and gains of use and cultural values of biodiversity		4. Explicit understanding of the relationship between changes in the metric's value and changes in the value of the biodiversity target		5. Include context-dependent information about conservation status, vulnerability, or irreplaceability of the biodiversity component(s)		6. Assumptions and rationale of the metric are clearly documented		
	S	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	
HH	5		2	- Only at the habitat level, although it assesses the number of trees. - Includes landscape variables	1		3	- Individual values are turned into one single final value - it is not possible to identify the cause or source of the change by only looking at the final metric's value	3	- Provides a measure of the area's quality	5	In Parkes, Newell, & Cheal, 2003.	0.63
UD	3	- When assessing habitat gain/loss, there is no condition assessment	1	- Only at the species level	1		5		5		4	When there is also no information on species global distribution, this needs to be estimated (area of occupancy), which can be inaccurate	0.57

Metric	BBOP attributes of suitable forms of metrics (2012)												TS1
	1. Capture type, amount, and condition or quality of the biodiversity that is being lost or gained		2. Quantify the losses and gains at the species, communities, habitats, and ecosystem levels within project's context		3. Enable the calculation of residual losses and gains of use and cultural values of biodiversity		4. Explicit understanding of the relationship between changes in the metric's value and changes in the value of the biodiversity target		5. Include context-dependent information about conservation status, vulnerability, or irreplaceability of the biodiversity component(s)		6. Assumptions and rationale of the metric are clearly documented		
	S	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	
UMAM	4	- Yes, but only through visual, qualitatively assessments	2	- Only at ecosystem level. - Includes landscape indicators, but through visual assessments	1		3	- Individual values are turned into one single final value - Not possible to identify the cause of the change with only the final value. - Based on qualitatively assessment, which makes it even more challenging	3	- Provides a measure of the area's quality	5		0.55
BSI	5		4	- Only at the habitat level, although it assesses the number of trees. - Includes landscape variables and conservation significance of species	1		3	- Individual values are turned into one single final value - Not possible to identify the cause of the change with only the final value.	4	- Provides a measure of the area's quality. - Addresses conservation significance	5		0.70

Metric	BBOP attributes of suitable forms of metrics (2012)												TS1
	1. Capture type, amount, and condition or quality of the biodiversity that is being lost or gained		2. Quantify the losses and gains at the species, communities, habitats, and ecosystem levels within project's context		3. Enable the calculation of residual losses and gains of use and cultural values of biodiversity		4. Explicit understanding of the relationship between changes in the metric's value and changes in the value of the biodiversity target		5. Include context-dependent information about conservation status, vulnerability, or irreplaceability of the biodiversity component(s)		6. Assumptions and rationale of the metric are clearly documented		
	S	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	
CSI	3	- When assessing habitat gain/loss, there is no condition assessment	1	- Only at the species level	1		5		5		3	- There is no method for determining the different included factors	0.57
US Wetland Banking	2	- Only amount	1	- Only at habitat level	1		3		1		3	- There is not an specific method for determining credits	0.47
US Conservation Banking	2	- Depends on method used for determining credits	1	- Habitat or species level	1		3		3	Depends, it if focus on acreage or individuals.	3	- There is not an specific method for determining credits	0.50

Metric	BBOP attributes of suitable forms of metrics (2012)												TS1
	1. Capture type, amount, and condition or quality of the biodiversity that is being lost or gained		2. Quantify the losses and gains at the species, communities, habitats, and ecosystem levels within project's context		3. Enable the calculation of residual losses and gains of use and cultural values of biodiversity		4. Explicit understanding of the relationship between changes in the metric's value and changes in the value of the biodiversity target		5. Include context-dependent information about conservation status, vulnerability, or irreplaceability of the biodiversity component(s)		6. Assumptions and rationale of the metric are clearly documented		
	S	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	**S**	**Notes**	
DEFRA metric	5		1	- Only habitat	1		2		3	- Provides a measure of the area's quality	5		0.57
MAM	3		1	- Only habitat	1		2		2	- Provides a measure of the area's quality	4	- Quality factors are not well explained	0.45
BV	3		1	- Only habitat	1		2		2	- Provides a measure of the area's quality	5		0.47
HU	3		1	- Only species	1		2		1	- No, since indicators are case-dependent	1	- No, since indicators are case-dependent	0.43
SEB	3		1	- Only species	1		1	- The condition indicators are turned into a ratio	2	- Provides a measure of the area's quality	3		0.43
Offset ratios	2		1	- Only ecosystems	1		1	- Value of the biodiversity target does not change	3		3		0.37

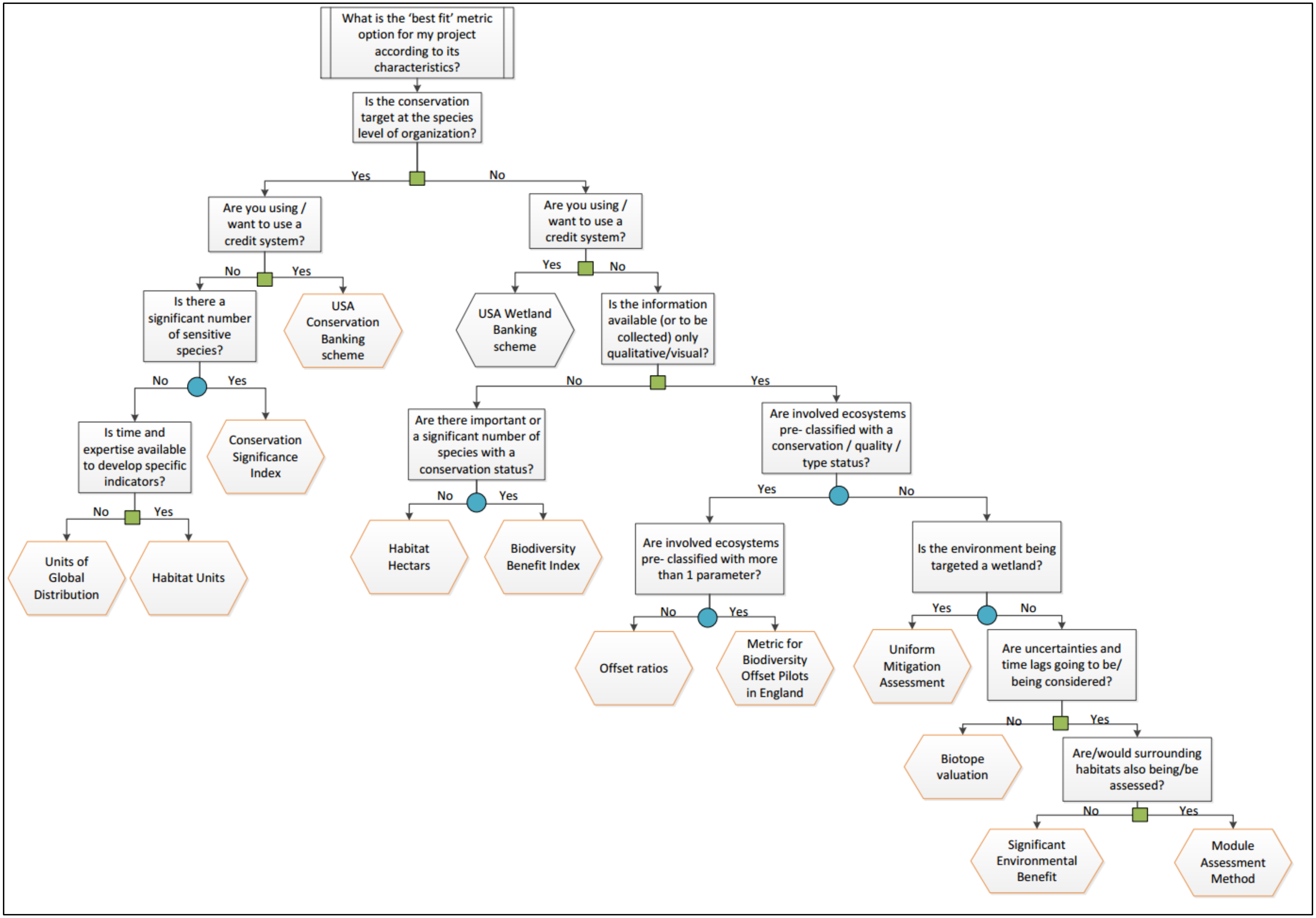
Metric	Stakeholders' criteria						TS2	FS3
	1. Level of organization of target: ecosystems / habitats	2. Objectivity	3. Benchmark consideration	4. Practicality	5.Indicators are biodiversity target dependent	6. Integration of "special values"		
	Score							
HH	1	1	1	0	0	0	3	1.90
UD	0	1	0	0	0	0	1	0.57

Metric	Stakeholders' criteria						TS2	FS3
	1. Level of organization of target: ecosystems / habitats	2. Objectivity	3. Benchmark consideration	4. Practicality	5.Indicators are biodiversity target dependent	6. Integration of "special values"		
	Score							
UMAM	1	0	0	1	0	0	2	1.10
BSI	1	0	1	0	0	1	3	2.10

Metric	Stakeholders' criteria						TS2	FS3
	1. Level of organization of target: ecosystems / habitats	2. Objectivity	3. Benchmark consideration	4. Practicality	5.Indicators are biodiversity target dependent	6. Integration of "special values"		
	Score							
CSI	0	1	0	0	1	1	3	1.70
US Wetland Banking	1	0	0	1	0	0	2	0.93
US Conservation Banking	0	0	0	1	0	0	1	0.50

Metric	Stakeholders' criteria						TS2	FS3
	1. Level of organization of target: ecosystems / habitats	2. Objectivity	3. Benchmark consideration	4. Practicality	5.Indicators are biodiversity target dependent	6. Integration of "special values"		
	Score							
DEFRA metric	1	0	0	1	0	0	2	1.13
MAM	1	0	0	1	0	0	2	0.90
BV	1	0	0	1	0	1	3	1.40
HU	0	1/0	1	0	1	0	2	0.87
SEB	1	0	0	1	1	0	3	1.30
Offset ratios	1	0	0	1	0	1	3	1.10

APPENDIX C: Decision tree for choosing the ‘best fit’ existing metric option


What is the 'best fit' metric option for my project according to its characteristics?
Is the conservation target at the species level of organization?
Yes
No
Are you using / want to use a credit system?
Are you using / want to use a credit system?
No
Yes
Yes
No
Is there a significant number of sensitive species?
USA Conservation Banking scheme
USA Wetland Banking scheme
Is the information available (or to be collected) only qualitative/visual?
No
Yes
No
Yes
Is time and expertise available to develop specific indicators?
Conservation Significance Index
Are there important or a significant number of species with a conservation status?
Are involved ecosystems pre- classified with a conservation / quality / type status?
No
Yes
No
Yes
Yes
No
Units of Global Distribution
Habitat Units
Habitat Hectars
Biodiversity Benefit Index
Are involved ecosystems pre- classified with more than 1 parameter?
Is the environment being targeted a wetland?
No
Yes
Yes
No
Offset ratios
Metric for Biodiversity Offset Pilots in England
Uniform Mitigation Assessment
Are uncertainties and time lags going to be/ being considered?
No
Yes
Biotope valuation
Are/would surrounding habitats also being/be assessed?
No
Yes
Significant Environmental Benefit
Module Assessment Method

APPENDIX D: Set of landscape indicators for characterizing the offsetting target

Objective	Criteria for characterizing offset target (TNC, 2003)	Attribute of biodiversity (Noss,1990)	Performance criteria	Relevance of performance criteria	Indicator	Unit	Range	Metric level
Achieve offset gains that are equivalent to project impacts in terms of size	Size	-	Equivalent/larger core area of targeted offset patch	- Core area is a much better predictor of habitat quality than patch area (McGarigal, n.d.). - Unlike patch area, core area is affected by patch shape and edge depth. - Thus, while a patch may be large enough to support a given species, it still may not contain enough suitable core area to support the species.	CAI - Core Area Index	%	0-100	Patch
Achieve offset gains that are equivalent to project impacts in terms of condition	Condition	Structure	Equivalent/lower dispersion of patches at offset area	- Dispersion refers to the spatial distribution of a patch type without reference to any other class. - The dispersion of a landscape is a fundamental aspect of landscape pattern and is important in many ecological processes: • The disaggregation of a patch type plays a crucial role in the process of habitat fragmentation. • One of the primary ecological consequences of aggregation seems to be related to edge effects. • The dispersion and interspersion of patch types may affect the propagation of disturbances across a landscape (Franklin & Forman, 1987).	CLUMPY - Clumpiness index	-	-1 - 1	Class
			Equivalent/lower interspersion of patches at offset area	- Interspersion refers to the spatial intermixing of different patch types (classes). - Interspersion is presumed to affect the quality of habitat for many species that require different patch types to meet different life history requisites. - The dispersion and interspersion of patch types may affect the propagation of disturbances across a landscape (Franklin & Forman, 1987).	IJI - interspersion / juxtaposition index.	%	0-100	Class

Objective	Criteria for characterizing offset target (TNC, 2003)	Attribute of biodiversity (Noss, 1990)	Performance criteria	Relevance of performance criteria	Indicator	Unit	Range	Metric level
Achieve offset gains that are equivalent to project impacts in terms of condition	Condition	Structure	Equivalent/lower subdivision of patches at offset area	- Deals with the degree to which patch types are broken up into separate patches. - The subdivision of a particular habitat type may affect a variety of ecological processes. E.g., determine the number of subpopulations in a spatially-dispersed population (Hanski & Gilpin, 1991), alter the stability of species interactions in both predator-prey and competitive systems, (Kareiva, 1990), etc. - Importance is related to the subdivision of populations and the disruption of landscape continuity and connectivity with implications for population persistence, ecosystem integrity and the spread of disturbances. - According to Wang, Clanchet and Koper (2014), subdivision metrics are useful to measure human penetration impacts.	SPLIT - splitting index	-	≥1	Class
			Equivalent/lower isolation of patches at offset area	- Deals with the degree to which patches are spatially isolated from each other. - Critical factor in the dynamics of spatially structured populations and communities (e.g., predator-prey dynamics, island biogeography). - Isolation is particularly important in the context of habitat fragmentation as it relates to the disruption of habitat continuity and connectivity. - Isolation is important to the spread of disturbances across the landscape as it can disrupt the continuity of susceptible patches.	CONNECT - Connectance Index	%	0-100	Class

Objective	Criteria for characterizing offset target (TNC, 2003)	Attribute of biodiversity (Noss, 1990)	Performance criteria	Relevance of performance criteria	Indicator	Unit	Range	Metric level
Achieve offset gains that are equivalent to project impacts in terms of condition	Condition	Function (biotic interactions)	Equivalent/lower proportional abundance of edge influenced habitat	- Edges are often responsible for increased predation, invasion of exotic plan species, and in many cases act as barriers for animal movement (McGarigal, n.d.). - The boundary between patches can function as a barrier to movement, a differentially-permeable membrane that facilitates some ecological flows but impedes others, or as a semipermeable membrane that partially impairs flows (Wiens, Crawford, & Gosz, 1985; Hansen & di Castri, 1992). - Can help to quantify the dynamics in the abundance and attributes of specific types of edges, and infer the associated ecological effects (Zeng & Wu, 2005)	ED - edge density	m/ha	≥0	Class
		Composition	Equivalent/higher landscape diversity at offset area	- While diversity expresses no information about the spatial configuration of the landscape, it expresses critical information about the landscape composition. - Landscape diversity is generally considered to be a factor contributing to landscape resilience or the ability to recover from disturbance and stressors.	SHDI - Shannon's diversity index	-	≥0	Landscape

Objective	Criteria for characterizing offset target (TNC, 2003)	Attribute of biodiversity (Noss, 1990)	Performance criteria	Relevance of performance criteria	Indicator	Unit	Range	Metric level
Achieve offset gains that are equivalent to project impacts in terms of landscape context	Landscape context	Function (processes and regimes)	Equivalent/higher shape complexity at offset area	- Size-shape relationship can influence a number of important ecological and environmental phenomena, such as animal dispersal, surface water runoff, speciation and extinction. - Patch shape has been shown to influence inter-patch processes such as small mammal migration (Buechner, 1989) and woody plant colonization (Hardt & Forman, 1989), and may influence animal foraging strategies (Forman & Godron, 1986). - The fractal dimension of patch shapes suggests a common ecological process or anthropogenic influence affecting patches across a wide range of scales, and differences between landscapes can suggest differences in the underlying process of pattern generation (Krummel, Gardner, Sugihara, O'Neill, & Coleman, 1987).	Perimeter-area fractal dimension PAFRAC	-	1-2	Landscape
		Structure (connectivity)	Equivalent/higher landscape connectivity at offset area	- Connectivity is considered a key element of the structure of landscapes (Taylor, Fahrig, Henein, & Merriam, 1993). - Useful indices of habitat fragmentation correlate strongly with the success of foraging, mate-finding, or dispersal processes (Schumacher,1996).	GYRATE_AM - Correlation length	m	≥0	Landscape

Indicator	Indicator description	Indicator strengths / benefits	References	Alternative indicators
CAI - Core Area Index	- Core area is a compound measure of shape, area and edge depth. - CAI measures the percentage of the patch that is comprised of core area (i.e., patch interior area after accounting for depth-of-edge effects defined by the user). - Treats edge as an area of varying width, and not as a line (perimeter).	'- This index does not confound area and configuration like the other core area metrics.	- Temple, 1986: found that core area was a better predictor of bird abundance than total fragment area. - Clark, Schmitz, & Bogenschutz, 1999: found that the size of the patch where ring-necked pheasants' nests were located was not sufficient to consistently predict success, being important to account for the core area in the landscape surrounding the patch. - Renfrew & Ribic, 2007: found that bird abundance increased with increasing core pasture in a fragmented system in Wisconsin. Core area was consistently important for higher bird densities, agreeing with several studies that found higher grassland bird densities on larger patches.	CORE - Core Area
CLUMPY - Clumpiness index	- Normalized index depicting the deviation from a random distribution; i.e., distinguishing distributions more uniform than random and more aggregated (or clumped) than random. - It returns a value of zero for a random distribution. - Lower values indicate higher disaggregation of patches	- Provides an effective index of fragmentation of the focal class that is not confounded by changes in class area. - Unaffected by the shape of the landscape. - Good for comparing different landscapes or the same landscape over time.	- Wang, Clanchet, & Koper, 2014: characterize this metric as one of the most promising ones in distinguishing between effects of habitat amount and fragmentation. - Nagendra, Pareeth, & Ghate, 2006: use this index to assess land fragmentation over time, finding a decrease in the index from 1989 to 2001, in an area experiencing increasing levels of fragmentation throughout that period.	AI - Aggregation Index COHESION - Patch Cohesion Index
IJI - interspersion / juxtaposition index.	- Extent to which patch types are interspersed as a % of the maximum possible, given the number of patch types, independent of their area. - Higher values result from landscapes in which the patch types are well interspersed.	- Not affected by resolution directly because only patch edges are considered	- Kumar, Stohlgren, & Chong, 2006: found that both native and non-native plant species richness are positively correlated with the interspersion/juxtaposition index. - Lausch & Herzog, 2002: used IJI to assess the arrangements of patches and land cover types in the landscape.	-

Indicator	Indicator description	Indicator strengths / benefits	References	Alternative indicators
SPLIT - splitting index	- Equals the number of patches of a landscape divided into equal sizes keeping landscape division constant. - Based on the cumulative patch area distribution - SPLIT = 1 when the landscape consists of single patch. SPLIT increases as the focal patch type is increasingly reduced in area and subdivided into smaller patches.	- Good indicator of overall species richness, especially woody plants (Schindler, von Wehrden, Poirazidis, Wrbka, & Kati, 2013). - Considered a relatively consistent, strong and universal indicator by Cushman, McGarigal & Neel (2008).	- Xu et al., 2013: among other metrics, SPLIT explained the highest % of total variation of landscape pattern in a study conducted in the Hani Terrace, China. - Li, Li, Zhao, & Yu, 2014: used SPLIT to assess the distribution of patches on a landscape over time.	DIVISION - Landscape Division Index MESH - Effective Mesh Size
CONNECT - Connectance Index	- The index measures the number of joins between patches of the same class, where each pair of patches is either connected or not based on a user-specified distance criterion. - CONNECT = 0 when either the focal class consists of a single patch or none of the patches of the focal class are connected. - CONNECT = 100 when every patch of the focal class is connected.	- User specifies the threshold distance (i.e., the distance between patches below which they are deemed connected. - Suitable for distinguishing between habitat amount and fragmentation for ecosystems where the focal habitat type is rare.	- Lesschen, Cammeraat, Kooijman, & Wesemael, 2008: used CONNECT to assess connectivity in a semi-arid ecosystem after land abandonment. They found an increase of the index with time since abandonment. - Ménard & Marceau, 2007: used CONNECT to assess connectivity of forest patches through time. The index decreased through time, as forest patches became increasingly isolated.	ENN_AM - Euclidean Nearest Neighbor Distance PROX_AM - Proximity Index SIM_AM - Similarity Index

Indicator	Indicator description	Indicator strengths / benefits	References	Alternative indicators
ED - edge density	- Density (m/ha) of edge of a particular patch type. - Sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m2), multiplied by 10,000 (to convert to hectares).	- Edge-based landscape metrics, especially edge density and edge segment density for specific edge types, can be used in conjunction with patch-based metrics to determine specific structure and function landscape dynamics (Zeng & Wu, 2005). - Reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size.	- Metzger & Muller, 1996; Metzger, 2000: Several studies have focused on the contribution of edge characteristics to the understanding of changes in landscape patterns and functions	TE - Total Edge
SHDI - Shannon's diversity index	- Based on information theory; represents the amount of 'information' per individual (i.e., patch type) - SHDI = 0 when the landscape contains only 1 patch (i.e., no diversity). - Larger values indicate a greater number of patch types and/or greater evenness among patch types.	- It is used as a relative index for comparing different landscapes or the same landscape at different times. - More sensitive to the presence of rare types than other similar indices and its interpretation is not as intuitive as in the case of similar indices.	- Nagendra, 2002: assessed the response of the SIDI and SHDI indices in two Indian landscapes. The results showed that the Shannon index is sensitive to the presence of rare cover types, and therefore is recommended for landscape management within an ecological framework; while Simpson’s index is more responsive to the dominant cover type.	SIDI - Simpson's diversity Index MSIDI - Modified Simpson's diversity Index

Indicator	Indicator description	Indicator strengths/benefits	References	Alternative indicators
Perimeter-area fractal dimension PAFRAC	- Provides an index of patch shape complexity across a wide range of spatial scales - If small and large patches alike have simple geometric shapes, then PAFRAC will be relatively low, indicating that patch perimeter increases relatively slowly as patch area increases. - Conversely, if small and large patches have complex shapes, then PAFRAC will be much higher. - Approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters	- The appeal of fractal analysis is that it can be applied to spatial features over a wide variety of scales (McGarigal, 2014)	- Krummel, Gardner, Sugihara, O'Neill, & Coleman, 1987; Milne, 1988; Turner & Ruscher, 1988; Iverson, 1988: use fractal dimension to characterize patch shapes in landscape ecological research. - Kandel, 2009: found that gradual decrease in the index may be due to conversion of forest patches into agriculture and bare land. - Krummel, Gardner, Sugihara, O'Neill, & Coleman, 1987: used PAFRAC to evaluate deciduous forest patterns in an area experiencing conversion to cropland. Found a clear relationship between PAFRAC and the proportion of anthropogenic land use. - Ouedraogo et al., 2011: found out that old forest and old cultivation presented lower values of FRAC_AM, while deforestation and reforestation presented the higher values.	SHAPE - Shape Index FRAC_AM - Fractal dimension index
GYRATE_AM - Correlation length	- Measure of patch/class extent across a landscape. - Provides a measure of continuity. Often interpreted as a measure of the physical connectedness of the landscape (structural connectivity). - Can be considered a measure of the average distance an organism can move within a patch before encountering the patch boundary from a random starting point. - Affected by both patch size and patch compaction. - Larger values indicate more connected landscapes.	- When combined with patch size, allows the user to assess the relative quality of patches found within a landscape. - Provides a means of quantifying connectivity that retains actual measurement units. - Useful when considering spatial scale of landscape.	- Yoder, 2004: found out that the decision to disperse in the fall by adult birds in 500 m buffered landscapes was best explained by the model containing this metric. - Carvalho, Junior, & Ferreira, 2009: found that the index was larger in landscapes dominated by the forest biome, when compared to areas of crops.	COHESION - Patch Cohesion Index CONTAG - Contagion Index

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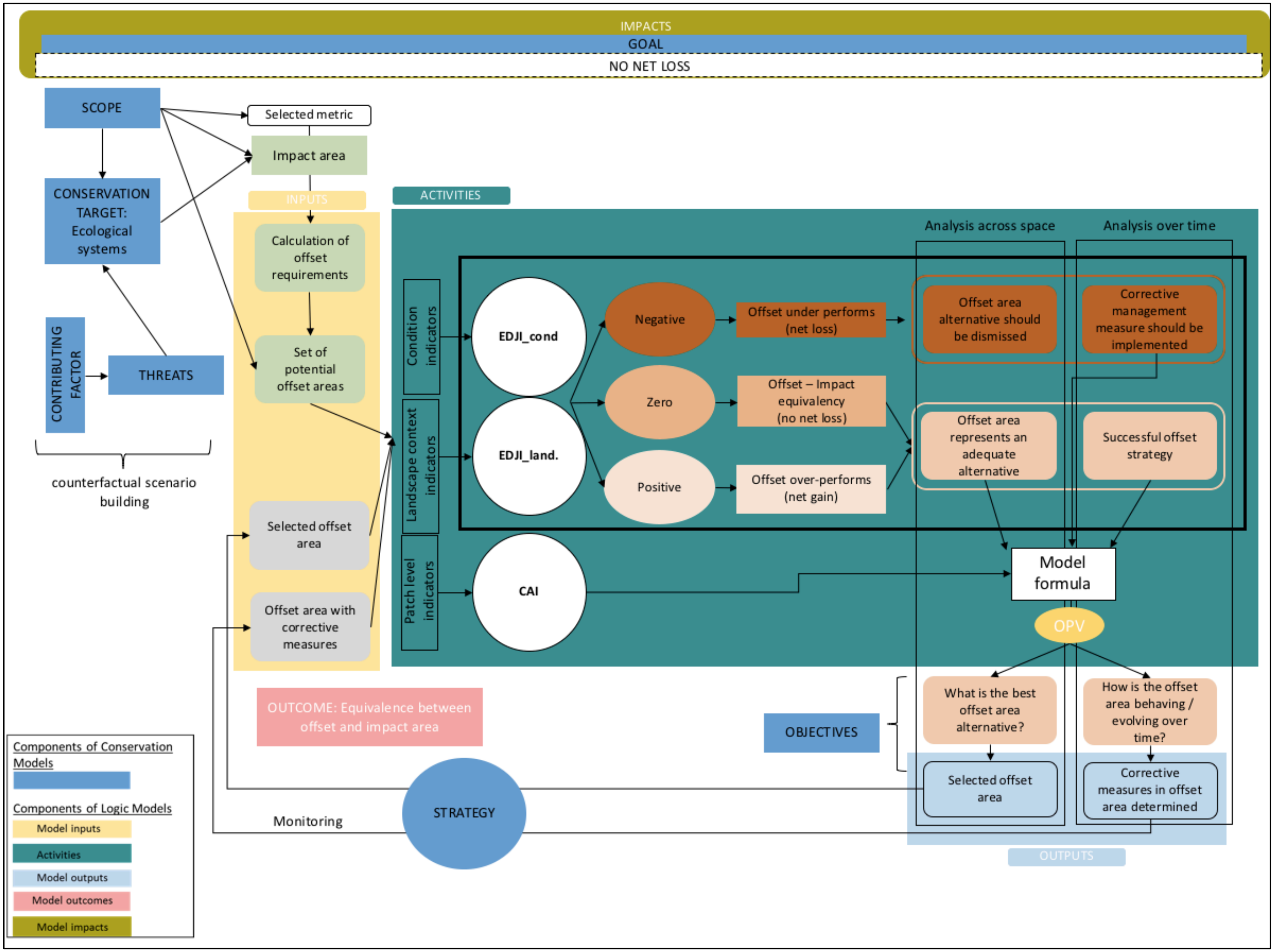
APPENDIX E: Visual representation of how the logic and conservation model components fit within the OPLM structure


IMPACTS
GOAL
NO NET LOSS
SCOPE
Selected metric
Impact area
CONSERVATION TARGET: Ecological systems
INPUTS
ACTIVITIES
Calculation of offset requirements
Set of potential offset areas
CONTRIBUTING FACTOR
THREATS
counterfactual scenario building
Analysis across space
Analysis over time
Condition indicators
Landscape context indicators
Patch level indicators
EDJI_cond
EDJI_land.
CAI
Negative
Zero
Positive
Offset under performs (net loss)
Offset – Impact equivalency (no net loss)
Offset over-performs (net gain)
Offset area alternative should be dismissed
Corrective management measure should be implemented
Offset area represents an adequate alternative
Successful offset strategy
Model formula
OPV
Selected offset area
Offset area with corrective measures
OUTCOME: Equivalence between offset and impact area
OBJECTIVES
What is the best offset area alternative?
How is the offset area behaving / evolving over time?
Selected offset area
Corrective measures in offset area determined
OUTPUTS
STRATEGY
Monitoring
Components of Conservation Models
Components of Logic Models
Model inputs
Activities
Model outputs
Model outcomes
Model impacts

APPENDIX F: Decision making tool for the implementation of successful biodiversity offset strategies in Latin America, their evaluation and regulation

STEP 1

VALIDATION OF CRITERIA & ATTRIBUTES THAT OFFSET METRICS SHOULD COMPLY WITH - STAKEHOLDER ENGAGEMENT

(1) Objective:	Validate the 'default' set of criteria and attributes (and/or identify new) that metrics for assessing the balance between impact losses and offset gains should comply with, according to the stakeholders involved in the project implementation, regulation and/or evaluation.

(2) Question:	What are the different criteria and attributes that metrics for accounting impact losses and offset gains should comply with, considering the context of the specific project?

(3) Participants:	Stakeholders involved in the implementation, regulation, and/or evaluation of the biodiversity offset project.

(4) Method:	Engage in dialogue and unstructured conversations with the stakeholders involved (in 3) to validate (and/or identify new) criteria/attributes. Table 1 can be used as a reference, validating/updating the criteria identified as part of my research.

TABLE 1

Reference criteria / attributes that metrics should comply with

Item	Default criteria	Validation		Other options
		YES	NO	
1. Target's level of organization	Ecological systems within a landscape context			Ecosystems / habitats
				Ecological communities
				Populations - species
				Genetic
2. Type of data required	Quantitative			Qualitative
3. Benchmark	Required			Not required
4. Integration of "special values	Necessary			Not necessary
5. General characteristics	Practical			
	Cost-effective			
	Indicators are target dependent			
	Others:			
6. Others:				

STEP 1 (continuation)

VALIDATION OF CRITERIA & ATTRIBUTES THAT OFFSET METRICS SHOULD COMPLY WITH - STAKEHOLDER ENGAGEMENT

<u>(5) Result:</u>	Set of relevant and validated criteria that metrics for assessing the balance between offset gains and project impacts should comply with (Table 2)

TABLE 2	
Validated set of criteria / attributes that metrics should comply with	
Criteria 1:	
Criteria 2:	
Criteria 3:	
Criteria 4:	
Criteria 5:	
Criteria 6:	
Criteria 7:	

STEP 2

METRIC SELECTION

(1) Objective:	Identify the best fit metric according to the characteristics of the specific project

-

(2) Question:	What is the 'best fit' metric for my biodiversity offset project?

-

(3) Participants:	Stakeholders involved in the implementation, regulation, and/or evaluation of the biodiversity offset project

(4) Method:	Complete steps 2.1 - 2.4:	
	Step 2.1	**Table A-1 (Appendix A):** Review the menu of existing metrics presented in Table A-1. This should be used to learn about the different types of existing metrics and how these differ.
	Step 2.2	**Table A-2 (Appendix A):** - This matrix provides information about how the different metrics presented in Table A-1 comply with what is expected in terms of the best practices for measuring ecological equivalences. It should be used to learn about how good or how poorly these satisfy relevant attributes and properties of "best biodiversity offset metrics". - In case it is necessary (according to the results of STEP 1), modify the "stakeholder's criteria" column of Table A-2. Characterize the metrics accordingly and determine the "best metric" according to the new final scores obtained.
	Step 2.3	**Figure A-1:** Use Figure A-1 (Appendix A) to determine the "best fit" metric for your specific project.
	Step 2.4	Validate the recommended metric using the information obtained from Steps 2.1 and 2.2.

(5) Result:	Determination of which biodiversity offset metric to use: ____

STEP 3 - Scenario 1

SELECTION OF BEST OFFSET AREA ALTERNATIVE

(1) Objective:	Select the most appropriate offset site from a set of potential offset areas (analysis across space).

(2) Question:	What is the best offset area alternative within a given landscape context?

(3) Participants:	Stakeholders involved in the implementation of the biodiversity offset project

<table>
<tr><td rowspan="15">(4) Method (OPLM):</td><td rowspan="5">- Inputs:</td><td>1. Calculation of offset requirements, using the metric selected as part of STEP 2</td></tr>
<tr><td>2. Set of potential offset areas that meet the offset requirements. These should be identified using the metric selected as part of STEP 2</td></tr>
<tr><td>3. Land cover maps of the study area</td></tr>
<tr><td>4. Identification of benchmark area</td></tr>
<tr><td>5. Delimitation of landscape boundaries for each of the offset areas, as well as for the impact area and benchmark areas</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">- Complete steps 3.1 - 3.5: use flow diagram presented in Figure A-2 (Appendix A) as a reference of the sequence of the activities involved in the OPLM.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Step 3.1</td><td>Table A-3 (Appendix A):
Select landscape indicators from Table A-3 for the analysis</td></tr>
<tr><td>Step 3.2</td><td>Calculate the selected indicators for the impact, benchmark, and set of potential offset areas using Fragstats and GIS tools</td></tr>
<tr><td>Step 3.3</td><td>Calculate the OPV for each offset area</td></tr>
<tr><td>Step 3.4</td><td>Use of multipliers, as necessary</td></tr>
<tr><td>Step 3.5</td><td>Rank the areas, and determine the best alternative</td></tr>
</table>

(5) Result:	Determination of best offset area alternative: ________________________________

STEP 3 - Scenario 2

MONITORING THE DEVELOPMENT OF A SPECIFIC ESTABLISHED OFFSET AREA

(1) Objective:	Monitor the development of a specific established offset area (analysis over time).

-

(2) Question:	How is the offset area behaving/evolving over time?

-

(3) Participants:	Stakeholders involved in the regulation and/or evaluation of the biodiversity offset project

<table>
<tr><td rowspan="12">(4) Method (OPLM):</td><td rowspan="4">- Inputs:</td><td>1. Selected offset area with/without corrective measures</td></tr>
<tr><td>2. Land cover maps of the study area</td></tr>
<tr><td>3. Identification of benchmark area</td></tr>
<tr><td>4. Delimitation of landscape boundaries for the offset, benchmark, and impact areas</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">- Complete steps 3.1 - 3.5: use flow diagram presented in Figure A-2 (Appendix A) as a reference of the sequence of the activities involved in the OPLM.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Step 3.1</td><td>Table A-3 (Appendix A):
Select landscape indicators from Table A-3 for the analysis</td></tr>
<tr><td>Step 3.2</td><td>Calculate the selected indicators for the impact, benchmark, and offset area using Fragstats and GIS tools</td></tr>
<tr><td>Step 3.3</td><td>Calculate the offset area's OPV</td></tr>
<tr><td>Step 3.4</td><td>Use of multipliers, as necessary</td></tr>
<tr><td>Step 3.5</td><td>Determine the need of implementing corrective measures. Amoeba diagrams could be constructed to aid in the identification of the key landscape aspects that could be strengthened/enhanced in order to improve the overall outcome, if necessary</td></tr>
</table>

<table>
<tr><td rowspan="3">(5) Result:</td><td>Is no net loss / net gain of biodiversity being achieved?</td><td>Yes</td><td>No</td></tr>
<tr><td>Why not? What landscape indicator exhibits the poorest performance in relation to the impact area?</td><td colspan="2">________________</td></tr>
<tr><td>What management strategy could be implemented to improve the results?</td><td colspan="2">________________</td></tr>
</table>

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